COMPARISON OF PRODUCTION AND NUTRITIONAL VALUE OF TWO SEED SOURCES OF WINTERFAT

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ABSTRACT

Winterfat, *Krascheninnikovia lanata* (Pursh) A.D.J. Meeuse & Smit, a native shrub that exhibits ecotypic variation, has been recommended for extending the grazing season into the fall, when protein levels are low in other plants of the northern Great Plains. A series of studies was established in 2001and 2002 at Swift Current, SK to examine developmental and nutritional differences between a northern seed source (Ducks Unlimited Canada ecovar™, DU) and a southern seed source (New Mexico, NM). Additionally, winterfat's nutritional contribution to mixtures containing alfalfa and western wheatgrass was examined. For the first experiment, plants were clipped once, at 50% of plant height, between June and snow fall. New Mexico winterfat was 8.7 % taller in 2002 than DU, but DU plants were more productive ($P < 0.05$) on a g m^{-2} basis (15% in 2002, 110% in 2003) than NM with more primary branches (40 % in 2002, 20% in (2003), higher fibre (4% in 2003) and decreased digestibility (7% for 3 year old plants) than NM. NM and DU plants had different ($P < 0.05$) crude protein, Ca, P, K, Na, Mn, Zn, Fe, Co, and Cd concentrations in 2002 and 2003. Supplementation of Ca, Cu, Co and Se for both seed sources and Zn for older NM plants would be required, to meet nutritional requirements of a medium framed British breed replacement heifer in its first trimester. Sulfur, Mg and Fe were in excess of animal requirements and may decrease Cu availability. In a study examining seed production of both seed sources as affected by fertilization and irrigation, DU plants produced seed in potentially commercial potential quantities while NM plants remained vegetative. Fertilizer and water had no effect on seed production ($P > 0.05$). The third study examining seeding mixtures of winterfat with alfalfa and western wheatgrass indicated that the mixtures provided adequate crude protein for a medium framed British breed heifer. Two *in sacco* experiments modelled a) digestion of the two winterfat types compared to alfalfa and western wheatgrass; and b) digestion of the same species as poly- or mono-cultures.

Alfalfa and NM winterfat, were similar, and had greater ($P < 0.05$) effective degradability than DU winterfat or western wheatgrass. The poly-culture feed mixture degradability of crude protein was greater ($P < 0.05$) than DU winterfat or Western wheatgrass. A positive synergy was observed for effective degradability of CP in mixtures. The studies overall demonstrate 1) northern and southern winterfat ecotypes have different growth and nutritional characteristics and 2) inclusion of alfalfa in mixtures with winterfat could provide adequate crude protein with a proportion (390 g kg^{-1} CP) being in the form of rumen undigestible crude protein.

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LIST OF ABBREVIATIONS

A	Alfalfa
AAFC	Agriculture and Agri-Food Canada
ADF	Acid detergent fibre
B	Boron
Ca	Calcium
Cd	Cadmium
Co	Cobalt
Cu	Copper
D	Slowly degradable fraction
DU	Ducks Unlimited
ED	Effective degradability
Fe	Iron
G	Western wheatgrass
K	Potassium
K_d	Rate of degradation of D
K_p	Rate of passage
Mg	Magnesium
Mn	Manganese
Mo	Molybdenum
Na	Sodium
NDF	Neutral detergent fibre
NM	New Mexico
OM	Organic matter
OMD	Organic matter digestibility
P	Phosphorous

RU	Rumen undegradability or rumen bypass
SPARC	Semiarid Prairie Agricultural Research Centre
S	Sulfur
Sf	Soluble fraction
Se	Selenium
SE	Standard error
St	Steer
T	Time
U	Undegradable fraction
WF	winterfat
Zn	Zinc

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CHAPTER 1
INTRODUCTION

1.1 Why Shrubs ?

The beef industry, particularly the cow/calf sector, has concluded that livestock production efficiency during the fall grazing season should be a high research priority. Sustainability and cost of livestock production during the fall and winter months in the Northern Great Plains can be improved by maintaining animals in the pasture compared with placing them in feedlots (Heitschmidt et al. 1996). Energy costs were lower when cattle instead of machinery were used to harvest the forage. In New Zealand Waghorn and Woodward (2004) reported higher levels of greenhouse gas production from feedlots compared to pastoral systems. Adams et al. (1996) indicated that extension of the grazing period into the fall/early winter period will result in reduced beef cow feeding costs and greater net returns to the cow/calf beef producer. Jensen et al. (2002) recommended that shrubs and forbs could provide a protein source in fall grazing and thus reducing the cost. In Europe, intensive livestock feeding facilities are considered unsustainable and alternative methods, such as pasture production, need to be found (Hodges 2003). A low-cost alternative to confined-feeding of animals was investigated in Pennsylvania where pasturing of dairy cattle increased profits by $85 to $185 US per cow per year. Research is ongoing to determine the best mix of forage species for pasture-based milk production (Suszkiw 2004).

Research on forage mixes for salt affected soils in Australia indicates that mixtures of grasses, legumes, and shrubs produce more sheep live weight and wool than monocultures by increasing the mixture's feed value (Masters 2002; Norman et al. 2002). In a greenhouse experiment, Schellenberg and Banerjee (2002) reported that winterfat (*Krascheninnikovia lanata* (Pursh) Meeuse & Smit) or saltbush (*Atriplex gardeneri* (Moq.) D. Dietr.) combined with alfalfa (*Medicago sativa* L.) could provide greater forage yield and quality than species monocultures . The use of multiple functional plant groups (i.e. grass, shrubs, and forbs) was suggested by Williams (1966) as a means of range improvement. Shrubs can contribute to both forage, quality and livestock production in pasture mixtures.

To improve sustainability and economics of cattle production in the Northern Great Plains region forage species must provide the nutritional levels required for the fall season. Most grasses are deficient in crude protein in the fall (Clarke and Tisdale 1945; McLean and Tisdale 1960; Smoliak and Bezeau 1967; Cook 1972; Jefferson et al. 2004) and low in nutritive value (Bezeau and Johnston 1962). Grasses have a higher digestible energy concentration than shrubs during periods of animal nutritional stress (winter periods or dry seasons) while shrubs are higher in protein (Otsyina et al. 1982; Cook 1972). Cook (1972) showed that the nutritive value of shrubs, forbs, and grasses decline as they mature but the comparative decline could be ranked grasses>forbs>shrubs for carotene, digestible protein, and phosphorous. Digestible energy decline with maturity had the opposite ranking. Therefore shrubs can improve late season nutritional quality if it is limited by low protein or phosphorous concentrations, this occurs frequently in the prairie region of western Canada.

Animals have higher requirements for nitrogen than plants because their tissues require protein as building blocks while plants store carbohydrates as fibre. As a result of these differences, nitrogen is frequently limiting in animal diets (Mattson 1980). Theurer (1974) found that range cattle diets had higher protein concentration than the bulk forage on the range due to selective grazing. This indicates animals recognise the need for increased protein and are spending energy to increase their protein intake. Protein supplementation has been suggested to improve nutritional status of foraging animals. Rittenhouse et al. (1970) found that beef cattle on winter-range in Nebraska responded better to protein supplementation compared to energy supplementation. Protein supplements can come in many forms but perennial plant sources are generally lower cost sources resulting from abundant supply and reduced transportation energy costs. Shrubs have been found to be an effective way to provide protein supplementation on pasture and rangeland (Sampson 1924; Otsinya 1984; Jones and Wilson 1987; Vallentine 2001).

Shrubs have potential to provide high protein forage during periods when other forage species are low in protein and they have been found to be a more consistent year-round source of nutrients than can be achieved with grasses and legumes (Rowe and Corbett 1999; Welsh 1989). For example, inclusion of old world winterfat boosted productivity of the native grass community in the Kopet Dag Piedmont (Prikhod'ko and Prikhod'ko 1984). In Australia shrubs of interest include species of the families Leguminosae (i.e. *Acacia*) and Chenopodiaceae (i.e. *Atriplex*) (Fetcher 1981, Graetz 1973). The Chenopod shrub saltbush (*Atriplex canescens* (Pursh) Nutt.) is the most commonly seeded forage species in the world (Le Houerou 1992) because it is seeded in most arid regions.

One advantage of shrubs lies in their ability to extract soil water and mineral resources from depth (Lee and Laurenroth 1994;Welsh 1989; Rowe and Corbett 1999; Jurena and Archer 2003; Schwinning et al. 2003). Soil water is the key limiting resource for many of these shrub species that are found in semiarid to arid environments.

Shrubs are known to exhibit other advantages, such as disease resistance (Smith 1896). Johnston et al. (1967) noted that the addition of forbs and shrubs to ruminant diets in the fall decreased urolithiasis due to their lower silica content than native grasses.

There are a number of native shrub species on the Canadian prairies but those found within the family Chenopodiaceae probably hold the most promise for extending the grazing season. One such species is *Krascheninnikovia lanata,* commonly known as winterfat, white sage or sweet sage. Smith (1896) suggested that it should be examined for its forage potential. Sampson (1926) stated "It would be difficult to name a browse plant of higher palatability or greater value as winter feed than winterfat. All classes of stock devour the seed, leafage, and young twigs with unusual relish...". Utilization has progressed in the U.S. where winterfat is the most commonly seeded dryland shrub on the Great Plains rangelands (Munshower 1995). To date, however, Canadian research has been limited. In the 1990's, at the Semiarid Prairie Agricultural Research Centre (SPARC) of Agricuture and Agri-Food Canada (AAFC) under Dr. J. Waddington, developed a Saskatchewan winterfat seed source with a diverse genetic background which was deemed an ecological variety or ecovar™. To date, work describing this material has been limited to germination requirements. Nutritional and agronomic studies have been limited to native material or seed supplied from the USA. The work detailed within these pages compares the recently developed Ducks Unlimited ecovar™ with the readily available and most common wild-harvested New Mexico seed (Wind River Seeds, personal communication).

CHAPTER 2
LITERATURE REVIEW

2.1 Geographic Range

According to the Integrated Taxonomic Information System (2004) there are three plant species to which the common name 'winterfat' applies. *Ceratoides aborescens* (Loisinsk.) C.P. Tsien & C.G. Ma is found in Inner Mongolia (Majerus 2002). *Ceratoides latens* (Gmelin) Rev. & N. Holmgren, commonly referred to as Pamirian winterfat or old world winterfat, is found on the Steppes of Ukraine, Kazakhstan, Eastern Russia, Central Europe, Central Asia, Eastern and Southern Spain. (Jager 1971; Tutin et al. 1980). *Krascheninnikovia lanata* (Pursh) A.D.J. Meeuse & Smit is found on 16 million ha of salt-desert shrublands in Western U.S. (Blaisdell and Holmgren 1984), as far south as Mexico (Springfield 1974), and north to Canada (Great Plains Flora Association 1986). The northern limit is disjunctive sites on Sheep Mountain in the Yukon Territory of Canada (Hoefs et al. 1975; Cody 1996) but *K. lanata* is not found in the neighbouring state of Alaska (Hulten 1968; Vetter 2000). Synonyms for *Krascheninnikovia lanata* are *Eurotia lanata* (Pursh) Moq., *E. lanata* var. *subspinosa* (Rydb.) Kearney & Peebles, *Ceratoides lanata* (Pursh) Howell, *C. lanata* var *subspinosa* (Rydb.) Howell and *C. lanata* var. *ruinina* Welsh (Harms 2003). The North American species, *K. lanata*, is the subject of this thesis.

Winterfat can be found in pure stands or in the following plant communities: pinyon-juniper, basin big sagebrush, Wyoming big sagebrush, and salt desert (Stevens and Monsen 2004). Winterfat frequently dominates upland or foot-hill sites usually in association with understory grasses (Stevens and Monsen 2004). Steven and Monsen (2004) noted winterfat dominates in three major salt desert shrub communities: winterfat-low rabbitbrush, winterfat-low rabbitbrush-grass, and winterfat-grass. Winterfat grows on soils with relatively low salt and sodium content. The soil textures vary from low-water-holding-capacity, coarse-textured soils to fertile and moist soils (Stevens and Monson 2004).

2.2 Ecotypic differences

Stebbins (1950) defined two types of variation within a species. Ecotypic variation is found in widespread species and results from a distinct genotypic response of a species to a particular habitat. Ecotypes are distinguished primarily by their reaction to their environment and not necessarily by morphological differences. The other type of variation is a cline which is a character gradient. Attributing variation to either ecotypic or clinal effects requires a comparison of traits among individuals from across the species' adaptive range. Winterfat literature specifically cites ecotypic variation for distinct 1) soil conditions; such as oil shale lands for Colorado/Wyoming material (Slauson and Ward 1982), salinity levels in Utah (Workman and West 1969; Clark and West 1971; Goodman 1973) and salinity combined with temperature in Utah (Workman and West 1967); and 2) freezing tolerance (Booth et al. 1999). Indications of ecotypic expression have been found in germination responses (Schellenberg 2003), fruit production, seed characteristics, above-ground biomass and tolerance to soil pH. (Stevens et al. 1977).

Variation in metabolic processes for imbibition, germination, and seedling growth suggested two ecotypic groups for winterfat, northern and southern populations, with the northern ecotype functioning best under cooler temperatures (Moyer and Lang 1976, Thygerson et al. 2002). Temperature response of germinants of three populations also suggested northern and southern ecotypes (Bai et al. 1998 a,b). Reidl et al. (1964) noted a wide range in seedling vigour for seed from New Mexico to Wyoming. Stevens et al. (1977) separated winterfat on the basis of growth characteristics, such as a large form, up to 1.5 m in height, found at higher elevations in mesic environments, a dwarf plant form found in more xeric environments of valleys which was 38 cm or less in height, and a northern dwarf growth form from the Yukon found on mountain tops with high precipitation but short growing season.

Comparative work with Canadian-sourced winterfat material is limited. Germination characterization studies have compared Saskatchewan-sourced seed with seed from southern USA (Bai et al. 1998 a,b; Booth et al. 1999; Thygerson et al. 2002; Schellenberg 2003). The Saskatchewan seed initiated germination processes under cooler temperatures and withstood freezing. Soil adaptation and productivity comparisons among ecotypes were reported in the U.S. but such information for Saskatchewan plants are lacking.

Epstein (1972) indicated that there are numerous examples of varietal differences and unexploited potential for ecotypical differences in mineral uptake. He also suggested that there was the potential for nutritional ecotypes to exist. Both these characteristics have not been studied previously for winterfat.

2.3 Growth

Germination of winterfat can occur with as little as 16 mm of precipitation (Ackerman 1979). Much of the initial growth of desert shrub seedlings occurs underground (Went 1948). Cavers and Harper (1967) indicated seedlings are more sensitive to interspecific competition than to environmental hazards. While Woodmansee and Potter (1970) indicated winterfat seedlings are sensitive to competition, they are more susceptible to grazing. This apparent difference in opinion may be due to time of grazing or age of plant community in which the winterfat occurred. Stevens and Monson (2004) note the competitive ability of winterfat depends on stage of growth, age, species in the plant community and edaphic conditions. Romo et al. (1995) found that regrowth originated from the crown of fall defoliated plants whereas winterfat defoliated in May, with a season of growth following defoliation, initiated spring regrowth from shoots produced during the previous year. Coyne and Cook (1970) found plant vigour was positively related to carbohydrate reserve storage at the end of the growing season.

The majority of growth for desert shrubs occurs at soil moisture concentrations below the permanent wilting point of many forbs and grasses (-1.5 MPa) (Love and West 1972). Winterfat transpires less than *Atriplex confertifolia* (Torr & Frem.) S. Wats. on a leaf area basis indicating better water use efficiency for winterfat plants although *A. confertifolia* remains physiologically active longer under dry conditions, and both transpired at -11.5 MPa soil water potential (Moore et al. 1971). Winterfat also has a lower overall physiological activity (degree of succulence and carbon assimilation) than *A. confertifolia* when under drought stress (Moore et al. 1972). Monsen and Stevens (2004) indicated that winterfat leaves and stems remain green year round. Bonham et al. (1990) found leaf conductance and transpiration were lower for winterfat than for two wheatgrasses grown in association with it. This is in agreement with the observation of Schwinning et al. (2003) that winterfat had lower levels of transpiration than many desert plants.

Roots represent the largest expenditure of assimilated carbon by winterfat plants because they are never dormant (Fernandez and Caldwell 1975). During a dry season Fernandez and Caldwell (1975) found that root growth occurred at soil depths to 80 cm for Utah-sourced plants. Solitary winterfat plants tend to have deeper roots than those with neighbours (Mack and Bonham 1988). Schwinning et al. (2003) noted that the rooting depth of winterfat was 20 cm or more, deeper than most grasses.

Increased soil moisture through mulches or irrigation can improve seed production of many recalcitrant species. Schellenberg (2002) found that the use of a weed barrier fabric, normally used for landscaping, increased winterfat seed production via decreased water loss from the soil surface. Hild and Morgan (1993) reported that mulches reduced evapo-transpiration and modified crown growth of shrubs such as winterfat. Majerus (2003) found irrigation at flowering, post-anthesis and post-harvest prior to freeze-up to be beneficial for winterfat seed production. Weingand et al. (2004) found that plant communities from semiarid environments of South Africa had a delayed growth response which was dependant on the previous years conditions, specifically moisture. However, excess water can have negative consequences. High precipitation was deemed responsible for a large winterfat die-off in the southwest US (Harper et al. 1990; Nelson et al. 1990).

Winterfat is not only adapted to dry but also cold environments with ecotypic differences in germinant development as mentioned previously. Walser et al. (1992) found Utah-sourced plants were able to withstand -80° C for stems and -35° C for buds.

Fertilizer application has been examined for improved biomass production of winterfat. Reidl et al. (1964) reported an increase (approximately 40%) in dry matter yield from the application of 50 kg ha^{-1} N and P compared to similar rates of K alone or P and K. Majerus (2003) utilized 45 kg ha^{-1} N and 22 kg ha^{-1} P to improve seed production but no data was provided. Photosynthesis and growth have been found to be greater for winterfat with addition of both N and water (Toft et al. 1989). Both water stress and N stress limit plant gas exchange in semiarid environments. From an experiment in which both N and water were manipulated in the semiarid environment of Idaho, the addition of N alone had a larger effect than additional water alone with the combined addition of N and water together being intermediate (Toft et al. 1989). Fertilizer may not always increase winterfat production. Winterfat plant numbers and leaf area index were not affected by N fertilizer (5 g m^{-2}) (Goodman 1973) for winterfat growing in Utah.

Kasach (1978) found that old world winterfat modified its growth form under grazing resulting in a prostrate plant with more annual vegetative shoots. However, grazing needs to be eliminated for successful winterfat seed production (Woodmanse and Potter 1970). Schellenberg (2002) found that seed harvesting, which produced excessive defoliation of winterfat, decreased seed production. Plants are modified by the environment but they in turn, modify the environment. West (1985) found winterfat had greater plant density and producing less litter than sage or salt bush. Winterfat had greater nutrient cycling and pooling of soil N beneath the plant than either sage or saltbush (West 1985; Romney et al. 1980). The resulting soil N patch can be utilized by other plant species (Duke and Caldwell 2001). Old world winterfat retains snow thereby accumulating moisture and increasing rangeland forage (Alimaev and Pryanishnikov 1989). The root system of winterfat overlaps with those of the grasses, *Agropyron smithii* Rydb. and *A. inerme* (Scribn. & J.G. Sm.) Rydb. which creates a parasitic opportunity for the grass roots to absorb soil water left by hydraulic lift by winterfat roots (Bonham and Mack 1987).

2.4 Mixtures

Seeded forage mixtures with multiple plant functional groups are a means to optimize soil resources used and forage quality from livestock production on pasture (Masters 2002; Norman et al. 2002; Suszkiw 2004). Ideally the forage stand should provide both an energy source and a protein source but be self sustaining. Dietary energy sources include plant fats, protein and carbohydrates. Carbohydrates are considered the most readily and economically available energy source for ruminant animals on pasture (Crampton and

Harris 1969). Energy and protein sources must be available in a synchronized manner (Orskov 1992) for efficient digestion. Animals grazing dormant tallgrass prairie required a balance of total degradable intake protein in relation to total digestible nutrients for optimal liveweight gain (Bodine and Purvis 2003). Lintzenich et al. (1995) concluded that inclusion of high protein alfalfa (*Medicago sativa* L.) supplements greatly increased utilization of low quality forage by grazing beef cattle. Bohnert et al. (2002) suggested that the rumen-undegradable crude protein in the range of 20 to 60% can be effectively used by beef cattle consuming low-quality forage.

Extension of grazing into the fall season requires adequate dietary energy and protein during a time period when the plants are dormant. Winterfat has been noted for its good fall crude protein concentration (Reidl et al. 1964; Smoliak and Bezaeu 1967). Jefferson et al. (2004) found western wheatgrass (*Pascopyron smithii* (Rydb.) A. Love) also had sufficient crude protein for the needs of a medium frame British breed cow in its first trimester of gestation. In Utah, winterfat improved feed value of crested wheatgrass pastures during the fall (Otsyina et al. 1982; McKell et al. 1990). Arthun et al. (1988) found improved nitrogen balance within the ruminant animal when shrub and forb leaves were added to a grass hay diet. Otsyina et al. (1982) found that a diet consisting of 69% winterfat was required to meet the gross energy requirements of sheep. Sheep have a smaller rumen volume than beef cows and therefore require higher protein and energy concentrations in their diets.

There are divergent opinions on what species are needed for a good plant community mix for cattle. Stevens and Monsen (2004) noted that species adapted to seeding with winterfat vary among climatic and edaphic conditions. They indicated winterfat can be considered a pioneer, early seral, or late seral species for the plant communities in which it was found. In all plant communities the mature winterfat plants were described as excellent competitors but seedlings were only moderately tolerant of competition in juniper-pinyon, four-wing saltbush, Basin big sagebrush, Wyoming big sagebrush, and black sage brush communities. Winterfat seedlings were listed as moderate to excellent competitors in shadscale, black greasewood and black brush communities. Pendery and Provenza (1987) concluded that in Utah when *Artemisia tridentata* Nutt., *Kochia prostrata* L. Schrad., and *Atriplex canescens* (Pursh) Nutt. were introduced into alfalfa and crested wheatgrass stands, interspecific competition had a greater impact on shrub survival than modifying grazing practices. Plant community improvement research in Colorado (Bonham and Mack 1987; Mack and Bonham 1988; Bonham and Mack 1990) suggests that western wheatgrass and winterfat would make a compatible revegetation mixture. Goeble and Cook (1960) classified winterfat as a good quality forage and western wheatgrass as fair. Rasmussen and Brotherson (1986) suggested that a slower growing grass, such as Indian rice grass (*Oryzopsis hymenoides* Roemer & J.A. Schultes) Recker ex Piper), would be less competitive with winterfat than more rapidly growing grasses. Schellenberg and Banerjee (2003) found in a greenhouse study that mixtures of alfalfa with winterfat or *Atriplex gardeneri* (Moq) D. Dietr. increased biomass compared to monoculture alfalfa. Including alfalfa in hay and pasture mixtures can elevate forage yield by a 100% or more (Leyshon 1978; Kreuger and Vigil 1979), with concomitant gains in livestock production (Hervey 1960; Kreuger and Vigil 1979). Kopp et al. (2003) found that incorporating alfalfa in meadow brome (*Bromus bieberstenii* Roemer & J.A. Schultes) pastures improved pasture carrying capacity by 28%, met nutritional requirements of lactating beef cows, did not entail financial risk, and was always a lower cost treatment when compared to fertilized grass pastures at Brandon, MB.

Much of the research reported in the literature deals with winterfat as a pre-existing component of a native range site but not a component to be seeded to develop an adequate nutritional forage source.

2.5 Nutritional Characteristics

Nutritive characteristics are known to change as plants mature during the growing season (Smoliak and Bezeau 1967; Cook 1972; Deinum 1973). Cook (1972) reported that forbs and shrubs retained protein, Ca and P concentrations better throughout their growth cycles than grasses, while grasses retained greater concentrations of digestible energy. These contrasting changes among functional groups contribute to our understanding of how more diverse pastures may lead to greater animal production. Forages with very low protein content have limited digestion due to nitrogen shortage (Deinum 1973; Orskov 1992).

For nutrients within forages to become accessible to the ruminant, rumen digestion must occur. Alfalfa is digested much more rapidly than grasses with a greater difference between leaf and stem digestibility occurring in alfalfa than in grasses (Deinum 1973). Lignified tissue can resist rumen microfloral digestion for up to 96 hours (Deinum 1973). Smith et al. (1972) found legumes to have greater dry matter and lignin concentration and lower hemicellulose concentration than grasses. Yu et al. (2003) found that the rapidly degradable protein fraction in alfalfa declines with advancing maturity but it increased for timothy (*Phleum pratense* L.). They also found alfalfa and timothy differ in carbohydrate composition and protein fractions and that the difference in structural versus non-structural components may be the reason for the higher nutritional value of alfalfa. Yu et al. (2004) also found the effective digestibility of both alfalfa and timothy decreased as they matured due to a reduced potentially degradable fraction and increased undegradable fraction. They noted no difference in alfalfa cultivars but a cultivar difference for timothy, indicating interspecific and intraspecific differences. In a mix of species therefore, one would expect to see a great deal of variation due to heterogeneity of species composition, tissue structure, and varying lignification of plant tissues (Deinum 1973).

Inclusion of shrubs to New Mexico forage diets provided a more favourable nitrogen balance (Arthun et al. 1988). Inclusion of shrubs and forbs in ruminant diets elicits few changes in ruminal digesta kinetics, because volatile fatty acid profiles and dry matter disappearance rates of shrubs are similar to alfalfa (Arthun et al. 1992a).

Throughout the literature, winterfat is recognized for its crude protein content. All three species of winterfat are known as good browse species for livestock and wildlife. Holechek et al. (1989) noted a higher total N, total available N and *in vitro* organic digestibility for winterfat leaf material than for grasses.

Nutritional characteristics found within the literature (Table 2.1) largely fail to provide source location, stage of development, plant parts or annual growth. Variation in quality between sources does occur but can not be accounted for with the information

Table 2.1: Nutritional characteristics as reprted within the literature

Characteristic	Crampton and Harris (1969)	Ensminger et al. (1990)	Hamilton and Gilbert (1972)	Goebel and Cook (1960)	NRC (1982)
Source of plants			Wyoming	Poor to good range condition	
Stage collected		fresh stem cured	plants in bloom		fresh stem cured
Total protein (g kg^{-1} DM)				84 - 112	
Crude protein (g kg^{-1} DM)	110	108	167.5		108
Crude fibre (g kg^{-1} DM)		158	292.2		
Nitrogen free extract (g kg^{-1} DM)			388.9		
Cellulose (g kg^{-1} DM)	250			204 - 212	
Lignin (g kg^{-1} DM)	90			84 - 112	100
NDF (g kg^{-1} DM)					720
ADF (g kg^{-1} DM)					440
Ash (g kg^{-1} DM)			126.6		
Ether extract (g kg^{-1} DM)		28	24.8	23 - 26	28
Gross energy (kcal kg^{-1})	3.9		4.19	3.74 - 4.06	
Digestible energy (kcal kg^{-1})		1.66			1.54
Ca (g kg^{-1} DM)	21.4	19.8		22.4 - 21.4	19.8
P (g kg^{-1} DM)	1.2	1.2		1.3 - 1.1	1.2
Carotene (mg kg^{-1} DM)	16.8	18.1			

provided.

Sowell et al. (1985) noted that cattle in the Wyoming Red Desert region preferentially grazed winterfat despite declining in nutritive value during the grazing season (from June to February). Crude protein declined from 176 to 73 g kg^{-1} DM, *in vitro* dry matter disappearance 750 to 370 g kg^{-1}, P 1.7 to 1.0 g kg^{-1} DM and K 24.5 to 4.7 g kg^{-1} DM but increased from Ca 11.7 to 16.2 g kg^{-1} DM. Smoliak and Bezeau (1967) reported that winterfat growing in Canadian *Stipa-Bouteloua* prairie region ranged from crude protein 231 to 121 g kg^{-1} DM , cellulose 263 to 326 g kg^{-1} DM, Ca 6.6 to 8.9 g kg^{-1} DM, P 2.8 to 1.2 g kg^{-1} DM and had a mean nutritive index value (NVI) of 26.0. Nutritive index value allowed comparison of forages to a standard of early-cut, chopped, dehydrated legume hay given a NVI rating of 100 when fed to sheep (Smoliak and Bezeau 1967). For comparison they also reported mean NVI values of 42.9 for western wheatgrass, 51.0 for crested wheatgrass and 48.0 for *Atriplex nuttallii*. Results from a study covering 16 sites including Brown, Dark Brown, Black and Gray soil zones of Saskatchewan found significant year effects on winterfat organic matter digestibility and protein content (Abouguendia 1998). For the period January to December monthly values were reported. The maximum and minimum nutritive values were 175 and 90 g kg^{-1} DM protein, organic matter digestibility of 670 and 520 g kg^{-1} DM, Ca 14 and 10 g kg^{-1} DM, and P 2.5 and 8.0 g kg^{-1} DM. For protein, organic matter digestibility, and phosphorous the maximum occurred in spring while the minimum occurred in late winter. Ca had the reverse trend. These values from the northern Great Plains differ considerably from preceding values from American researchers. The Canadian values are considerably greater, suggesting that the observed differences are possibly due to site or plant type, but no reports were found within the published literature to confirm or disagree with this observation. Abouguendia (1998) noted variations due to site or region within Saskatchewan, so US vs Canadian source differences should be expected.

Few anti-nutritional compounds have been reported for winterfat. Sanderson et al. (1988) reported that winterfat had flavones that were liberated by acid hydrolysis but contained no saponins. Holechek et al. (1990) noted a low tannin concentration of 0.4

catechin equivalent per 100 mg organic matter.

Minerals are required for good nutrition in foraging animals and can be divided into essential major minerals: Ca, Cl, K, Mg, N, Na, P and S; nutritionally essential minor and trace elements B, Br, Fe, I, Si; and toxic with essential/toxic duality for As, Cd, Co, Cr, Cu, F, Hg, Mn, Mo, Ni, Pb, Pd, Se, Sn, Tl, V and Zn (Ihnat 2003). Forages obtain these elements from the soil and grazing animals ingest them in turn from the plants. Animal nutritional requirements vary according to animal species (Crampton and Harris 1969) and there is some indication of breed differences within species (Mullis et al. 2003). Environment can affect mineral uptake by forage plants. For example, Soder and Stout (2003) found in Pennsylvania that forage P concentration was not affected by soil type while K concentration was. They also found that slurry manure application increased Mg and Ca concentration and that Mg concentration was also affected by soil type. Ganskopp and Bohnert (2003) noted significant interactions between Ca, Mg, P, K, Cu, Zn, Mn and Na concentration and year, with dry years exhibiting increased mineral concentrations in 7 northern Great Basin grasses.

Springer et al. (2002) noted a scarcity of research regarding trace mineral concentration in browse species. Epstein (1972) similarly noted there were few studies on mineral nutrition of wild plants. Winterfat is no exception because mainly Ca and P concentrations have been reported to date. Winterfat leaves from a site in Nevada, USA contained the following macromineral concentrations in g kg^{-1} DM: N 36.2, P 2.2, Na 0.37, K 36.9, Ca 14.2 and Mg 5.6 (Romney et al. 1980). Micromineral concentrations in mg kg^{-1} DM were: Zn 21, Si 0.05, Cu 4, Fe 110, Mn 66, B 41, Sr 45 and Ba 5 (Romney et al. 1980). Hamilton and Gilbert (1972) noted that variation in mineral concentration occurred due to genera, soil types and locations for a number of Wyoming range plants and that browse species compensated for mineral deficiencies in the grasses. Romney et al. (1980) noted that shrubs redistribute minerals in Mojave desert soils because Na, K, Ca, Mg, Cl, nitrate, sulfate, DPTA-extractable Fe and Mn accumulated in the soil under shrubs. But shrub species do not all concentrate the same minerals nor in similar amounts. For example, Moore et al. (1972) found that *Atriplex confertifolia* accumulated soil Na and winterfat did not while both shrubs accumulated soil K. Wallace (1989) noted that different species of shrubs accumulated minerals differently even when grown side by side. Wallace and Romney (1972) reported that Zn, Fe and Al concentrations in winterfat were higher than for other shrub species. Additional trends that they reported were: K concentration was greatest during active growth while Ca concentration decreased; Zn, Cu, Fe, Mn and Al concentrations decreased during leaf growth; and winterfat growing on slightly salty soil did not accumulate Na. Stark and Redente (1990a) found that winterfat accumulated Mo when grown on retorted oil shale disposal piles. Copper fertilization decreased the potential of molybdenosis (Stark and Redente 1990b) as does Cu supplementation (Minson 1990). Molybdenosis occurred when the Cu/Mo concentration ratio was less than 2.0 (Miltimore and Mason 1971).

From the above discussion it is again apparent that previous research compared species but no mineral concentration comparisons among ecotypes within winterfat have been reported.

2.6 Utilization

Winterfat is relished by livestock, especially sheep and cattle. Winterfat has been chiefly used as a winter forage (Dayton 1931). Maintaining palatable forbs and shrubs, such as winterfat, should reduce the need to provide protein supplements when grasses are dormant (Arthun et al. 1992 a,b). But what level of utilization will result in sustainable plant communities? Reidl et al. (1964) noted a marked increase in winterfat biomass under light to moderate grazing and a moderate increase with heavy grazing compared to no grazing. Holmgren and Hutchings (1972) also found an increase in winterfat productivity under grazing. Hodgkinson (1975), in an evaluation of winterfat, found that it survived 80% defoliation by clipping in fall. Old world winterfat has been found to have increased blossoming with 50-70% utilization by graziers (Pen'kova 2000). Williams (1985)recommended heavy defoliation stress followed by one or more seasons of rest for winterfat. Using model simulations, Fetcher (1981) determined that winterfat maintained itself with 25% spring and 50% winter removal but was unable to maintain itself with 50%

spring removal. Cook and Child (1971) found early spring harvesting significantly less harmful than late spring. Stevens and Monson (2004) noted winterfat's tolerance to winter grazing is remarkable. However, persistent and continuous overgrazing particularly in spring and summer will reduce winterfat density to levels of elimination. Romo et al. (1995) suggested that more than a year was required for recovery on the Canadian prairies after clipping plants once to a height of 5 cm during the growing season. They also noted that the impact of grazing during dormancy is not known for the Northern Great Plains. In Montana, mowing to a 10 cm stubble did not prevent seed production the following year (Majerus 2003) contrary to findings in Saskatchewan where extensive defoliation for seed harvest resulted in only vegetative growth in the next year (Schellenberg 2002). These results suggest regional and possibly ecotype differences within winterfat for defoliation tolerance and utilization recommendations.

2.7 Seed Availability

Winterfat can be wild harvested throughout its range with appropriate land owner permission and this is the main available source of seed. New Mexico seed is the most readily available (Wind River Seeds, personal communication). In the United States there are three germplasms available through USDA-NRCS : Hatch from Los Lunas Plant Materials Center, New Mexico; Northern cold desert germplasm released by Aberdeen Plant Materials Center and Idaho Agricultural Experiment Station; and Open range germplasm released by Bridger, Montana Plant Materials Center (Ogle et al. 2003). Northern cold desert and Open range germplasms were made available after the work within this thesis was initiated.

In co-operation with the Semiarid Prairie Agricultural Research Centre (SPARC) - AAFC, Ducks Unlimited Canada (DU) have developed an ecovar™ or ecological variety of Saskatchewan source germplasm for western Canada. The ecological variety was intended to have a greater genetic diversity than a cultivar. The winterfat ecovar was made up of seed collected from 16 sites in southern Saskatchewan. The resulting plants were grown in a nursery at SPARC. The seed harvested from the SPARC nursery was then bulked and released for seed increase as the winterfat ecovar.

2.8 Hypotheses to be Tested

There are knowledge gaps with regard to possible nutritional differences, growth differences and possible utilization within the Canadian prairie context for winterfat plants from contrasting seed sources. Therefore the intent of this thesis is to test the following hypotheses:

1) New Mexico and Ducks Unlimited seed sources grown in Saskatchewan will not result in plants possessing similar growth and nutritional characteristics. Null Hypothesis: New Mexico and Ducks Unlimited seed sources grown in Saskatchewan will result in plants possessing similar growth and nutritional characteristics.

2) Inclusion of winterfat in a forage species mix will result in improved nutritional quality for fall grazing. Null Hypothesis: Inclusion of winterfat in a forage species mix will not result in improved nutritional quality for fall grazing.

2.9 Objectives to Test Hypotheses:

(I) Compare growth characteristics between DU and New Mexico seed when grown in Saskatchewan.

(II) Determine the seed production potentials of the two seed sources and if seed production is increased by fertilization and irrigation.

(III) Determine if the two sources of winterfat grown in Saskatchewan differ in nutritive value.

(IV) Determine if inclusion of winterfat with alfalfa and western wheatgrass meets nutritive needs of livestock.

(V) Determine if fall harvested winterfat differs in digestive character by seed source or from monocultures of alfalfa and western wheatgrass or changes the digestive kinetics of species mixtures.

The objectives were addressed in a series of experiments described in Figure 2.1.

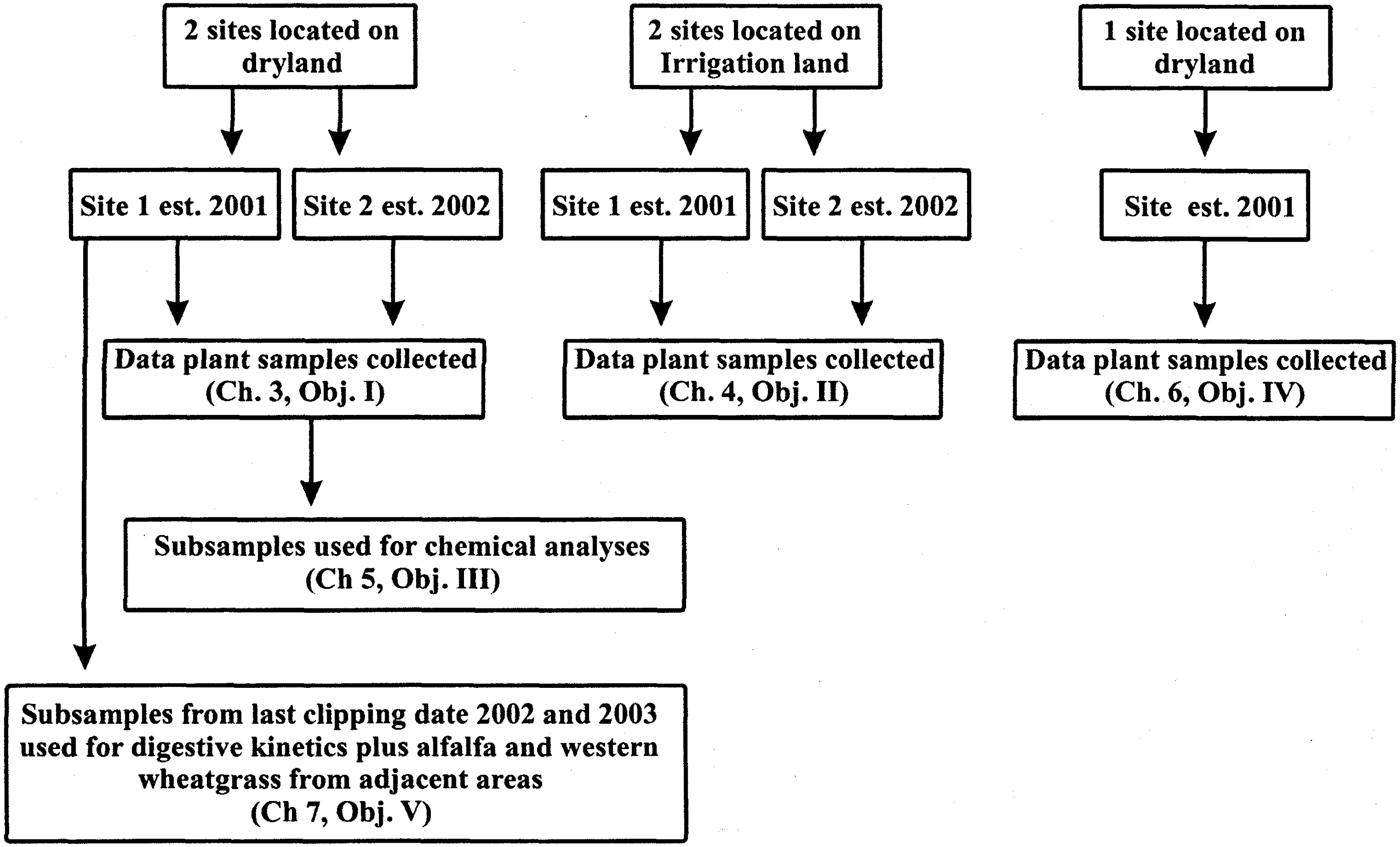

Figure 2.1: Flowchart describing manner in which objectives were addressed.

CHAPTER 3
PHENOLOGICAL DIFFERENCES BETWEEN DUCKS UNLIMITED AND NEW MEXICO SEED SOURCES

3.1 Introduction

The semi-shrub winterfat, *Krascheninnikovia lanata* (Pursh) A.D.J. Meeuse & Smit, is known for its high nutritive value as a winter forage (Sampson 1924; Smoliak and Bezeau 1967; Abouguendia 1998).Winterfat is a shrub found from Mexico (Springfield 1974) to Canada (Great Plains Flora Association 1986) as far north as Sheep Mountain in the Yukon (Hoefs et al. 1975), but not Alaska (Vetter 2000).

Within its distribution range, winterfat exhibits ecotypes due to soil (Workman and West 1969; Goodman 1973), and salinity (Clark and West 1971). Ecotypic variation can be demonstrated in productivity for fruit, seed characteristics, above-ground productivity and degree of tolerance of soil pH (Stevens et al. 1977). Stebbins (1950) defined ecotype as: a distinct genotypic response of a species to a particular habitat, commonly found in widespread species. The response is not necessarily morphological in nature. Epstein (1972) indicated there are numerous examples of varietal differences and unexploited potential for ecotypic differences in mineral uptake. He suggested that nutritional ecotypes may exist in many species. Nutritional ecotypic characteristics have not been reported in the literature for winterfat.

Stevens et al. (1977) classified potential winterfat ecotypes on the basis of growth characteristics, such as a large stature ecotype, which is up to 1.5 m in height and found at higher elevations in mesic environments, a dwarf plant form which is 38 cm or less in height and found in more xeric environments of the valleys, and a northern dwarf growth form found on mountain tops of the Yukon with high precipitation and short growing season. These growth variants are defined by location and raise the question: if a tall stature plant from the southern portion of the species range is grown under the same conditions as a northern dwarf form, do the growth forms remain unchanged?

Germination responses to temperature indicate inherent adaptations to withstand cold for Saskatchewan plants (Booth et al. 1999; Schellenberg 2002; Thygerson et al. 2002). Thygerson et al. (2002) indicated additional research was required to determine if similar inherent adaptations were present in more mature winterfat plants. Walser et al. (1992) suggested that increased cold adaptation occurred in older plants found in Utah but this also suggests that cold sensitivity can occur in southern ecotypes of winterfat. It is not known if this sensitivity to cold temperature expresses itself at other growth stages besides germination. Larcher (1995) indicated that the progression through phenological development, from vegetative growth to flushing and flowering, is greatly influenced by temperature.

Defoliation has been reported to increase biomass production (Reidl et al. 1964, Holmgren and Hutchings 1972), although Romo et al. (1995) found in Saskatchewan that when plants were defoliated to a height of 5 cm production decreased during the following growing season. Majerus (2003) noted no decrease in seed productivity with a late season defoliation in Montana where plants cut to10 cm. As Romo et al. (1995) noted, there has been no work in the Northern Great Plains examining the impact of late season defoliation on winterfat regrowth or seed production.

Winterfat seed can be harvested from wild plants throughout its range with appropriate permission and this is the main source of seed, with New Mexico seed being the most readily available (Wind River Seeds, personal communication). In the United States, through USDA-NRCS, there are currently three germplasms or seed sources available: Hatch from Los Lunas Plant Materials Centre, New Mexico; Northern cold desert germplasm released by Aberdeen Plant Materials Centre and Idaho Agricultural Experiment Station; and Open range germplasm released by Bridger, Montana Plant Materials Center (Ogle et al. 2003). At the time of initiation of this work only Hatch was available.

In co-operation with the Semiarid Prairie Agricultural Research Centre (SPARC) - AAFC, Ducks Unlimited Canada (DU) have developed a winterfat ecovar™ or ecological variety of Saskatchewan source germplasm for western Canada. The ecological variety was intended to have a greater genetic diversity than a cultivar. The winterfat ecovar was made up of seed collected from 16 sites across southern Saskatchewan. The resulting plants were grown in a field plot nursery at SPARC. The seed harvested from the SPARC nursery was then bulked and released for seed increase as the winterfat ecovar™ . There was no selection imposed for agronomic characteristics such as seed production, grazing tolerance or nutritional qualities.

Descriptions of the USDA germplasms, for example Open Range, have been reported (Majerus 2002) but not for the Ducks Unlimited ecovar™ (DU). Information about the growth characteristics of the DU ecovar™ is required before it can be recommended as a forage for livestock and seed production by the seed industry.

The objectives of this study were to compare growth characteristics of two contrasting plant types: a southern (New Mexico) winterfat wild plant type and a northern (Saskatchewan) plant type (DU ecovar™), and to provide a description of growth for the DU Canada ecovar™.

3.2 Materials and Methods

Two, three-factor factorial design (Figure A1), experiments with four replicates were established at the Semiarid Prairie Agricultural Research Centre at Swift Current, Saskatchewan (50° 17′ N, 107° 41′ W; elevation 825 m) on a Swinton loam soil (Orthic brown chernozem) (Ayres et al. 1985).

3.2.1 Experiment 1

The first experiment (site 1) was established in 2001 and had plots of 10 transplanted plants (NM or DU) spaced 0.5 m apart in the row and placed in weed barrier landscape fabric (supplied by the Professional Gardener Co. Ltd., Calgary, AB.) (Figure A1). The rows were separated by 1 m of fabric covered soil. Transplants started in the greenhouse January 2001 were transplanted into the weed barrier fabric in June 2001. Replacement of dead plants only occurred in spring of the year after initial transplanting prior to clipping. Replacements, in 2002, were 22% of NM and 13% of

DU. Transplants used for replacement were from the same seed batch and approximately the same age, having been maintained in the greenhouse for this purpose. Samples were collected from two-year-old plants (2002, first harvest) and three-year-old plants (2003, second harvest).

For the full factorial experiment (Figure A1), the factors were: 1) seed source: New Mexico (NM; seed supplied by Wind River Seeds, Wyoming) or Saskatchewan (DU; Ducks Unlimited Canada ecovar™); 2) clipping dates (end of each month): six dates, June to November in 2002, and five dates, June to October, in 2003; and 3) two rates of fertilizer: zero or 100 kg N ha^{-1} with 50 kg ha^{-1} phosphorous (P) as P_2O_5. Fertilizer rates for N and P were within the range recommended for cultivated Saskatchewan forage crops (Murrell 1992). Soil available N and P were determined by automated hydrazine reduction extraction and automated acid molybdate/ascorbic acid extraction (Winkleman 1998) of soil samples prior to addition of fertilizer in late June.

A number of growth parameters were measured and recorded when biomass was harvested using a hand sickle. These included: biomass yield, height, canopy diameter, branch diameter and number of primary and secondary branches. Clipping removed 50% of the growth by height and the harvested material was referred to as biomass production. Clipped materialincluded current and previous year's growth, as livestock do not to selectively graze winterfat biomass based on year of growth (personal observation). Clipping commenced the year after establishment or the second year of growth. All clipped material was dried in forced air ovens (set at 60° C) to a constant weight. Individual plants were weighed and then combined to make a bulked plot sample for subsampling. Dry matter yields for individual plants were recorded to provide comparison of individual plant production that was unaffected by survival and plot dry matter yields were recorded for potential area production that was affected by individual plant survival. Dried samples were ground in a Wiley mill to pass through a 1 mm screen, labelled and placed in glass jars.

Immediately before clipping, the standing height was measured for all live plants and the growth stage was recorded (Table A1). On three randomly selected plants per plot, two canopy diameter measurements were taken with the second measurement perpendicular to the first. Clipping occurred on the same date, in the same manner and same sequence for both 2002 and 2003. During the second year of growth, the primary and secondary branches of three randomly selected plants per plot were counted. In the third year of growth, the primary branches were counted and primary, secondary and tertiary branch diameters were obtained for three randomly selected branches of each type from three randomly selected plants per plot. In 2003, leaf:stem ratios were obtained for 15 cm lengths of shoot with a complete growing point. Three leaf lengths and widths from three random branches were used for dimension measurement. Leaves selected for measurement were 1 cm from the tip, midway and 1 cm from the bottom of the branch.

3.2.2 Experiment 2

Approximately 500 m north of site 1, the second experiment (site 2) was established in 2002 with the same layout (Figure A1). Samples were collected in 2003 from two-year-old plants at site 2. Replacement of dead plants only occurred in spring of the year after initial transplanting prior to clipping. Co-incidentally replacements, in 2003 (the first year of harvest for experiment 2), were 22% of NM and 13% of DU, the same percentages as in experiment 1. Transplants used for replacement were from the same seed batch and approximately the same age, having been maintained in the greenhouse for this purpose.

Samples and data were collected as for experiment 1 in 2002 (first harvest for experiment 2). In addition, leaf:stem ratios were obtained for 15 cm lengths of shoot with a complete growing point. Three leaf lengths and widths from three random branches were used as described for experiment 1.

3.2.3 Meteorological Data

Daily mean temperatures, precipitation and potential evaporation (US Weather Bureau Class A pan) were obtained from the weather station approximately 1 km away.

3.2.4 Statistical Analyses

Data were tested for fit to normal distribution using the Shapiro-Wilk test (SAS 1999). All data were statistically analysed for all main factors, two and three way interactions using ANOVA for individual years using Proc GLM (SAS Institute, Inc. 1999). Standard error (SE) was calculated for means (Steel and Torrie 1980). Individual year means were compared using a t-test (Montgomery 1997). The stage of growth was rated with a numeric score (Table A1), analyzed using ANOVA for individual years using Proc GLM (SAS Institute, Inc. 1999) and the mean result converted back to a descriptive stage of growth. When the factor or interaction was significant at $P < 0.05$, Tukey's test was used for mean separation (Steel and Torrie 1980). Only significant interactions are discussed.

3.3 Results and Discussion

Results of the Shapiro-Wilk test indicated that the data were normally distributed, except the leaf/stem ratio. Leaf/stem data were transformed using the square root transform (Steel and Torrie 1980). Variance decreased but no difference occurred for F-test probabilities and therefore untransformed analysis results are reported for simplicity.

3.3.1 Meteorological Data

The first year, 2001, was drier than the long-term average for SPARC while the second year, 2002, provided above average precipitation (Figure 3.1) especially during June and August. The growing season for 2003 was the third lowest total precipitation in 117 years, with the period from 21 June until 15 September recording only 50 mm (Judeisch 2004). The years 2001 and 2003 (January to December) were warmer than the long term average (Figure 3.2) with 2003 being the 5th warmest year on record (Judeisch 2004). The year 2002 proved to be below the long term average in temperature. Potential evaporation (Figure 3.3) reflects the precipitation and temperature experienced during the years. Potential evaporation was above average during the dry month of May for 2001 and 2002 and well above average for the month of August during 2001 and 2003. Only 2001 had above average evaporation in September. The year 2003 exhibited above average potential evaporation for most of the growing season (June to August). Well-below average evaporation was recorded in August 2002. In summary, the 2001 and 2003 growing seasons were warm and dry but the 2002 season was cool and wet.

3.3.2 Canopy Structure and Biomass

3.3.2.1 Experiment 1

3.3.2.1.1 First Year of Harvest 2002

3.3.2.1.1.1 Seed Source

The seed sources differed ($P < 0.05$) only for the number of secondary branches, plant height and dry matter yield per plant (Table 3.1) . The DU ecovar™ exhibited more secondary branches than NM while the NM seed source plants were taller and had greater individual plant biomass possibly due to increased resources, such as soil moisture, resulting from fewer surviving plants. Although not significant ($P > 0.05$) DU plants tended to produce more biomass m^{-2} than NM. This trend was due to the greater number of surviving plants per plot for DU compared to NM. The increased number of branches combined with shorter DU plants would result in compact plants. With both compact plants and increased number of plants, there may be an increase in grazing efficiency because animals could obtain more material per bite. The increased density of the forage presented to the grazing animal could contribute to increased bite weight and the rate of intake (Vallentine 2001).

3.3.2.1.1.2 Clipping Date

In 2002, clipping date had a significant impact ($P < 0.05$) on plant measurements which included: canopy diameter, plant height, branching, and dry matter yield for both individual plants as well as per plot (Table 3.1). The clipping date effects were expected due to progressive growth throughout the growing season. Growth stopped in September when night temperatures dropped below 5°C. Maximum branching and plant height were achieved by the July date. A reduction occurred in canopy diameter with snowfall in October. There also appears to be a loss of branches and height during September and October which may have been due to damage resulting from compaction by wet snow cover.

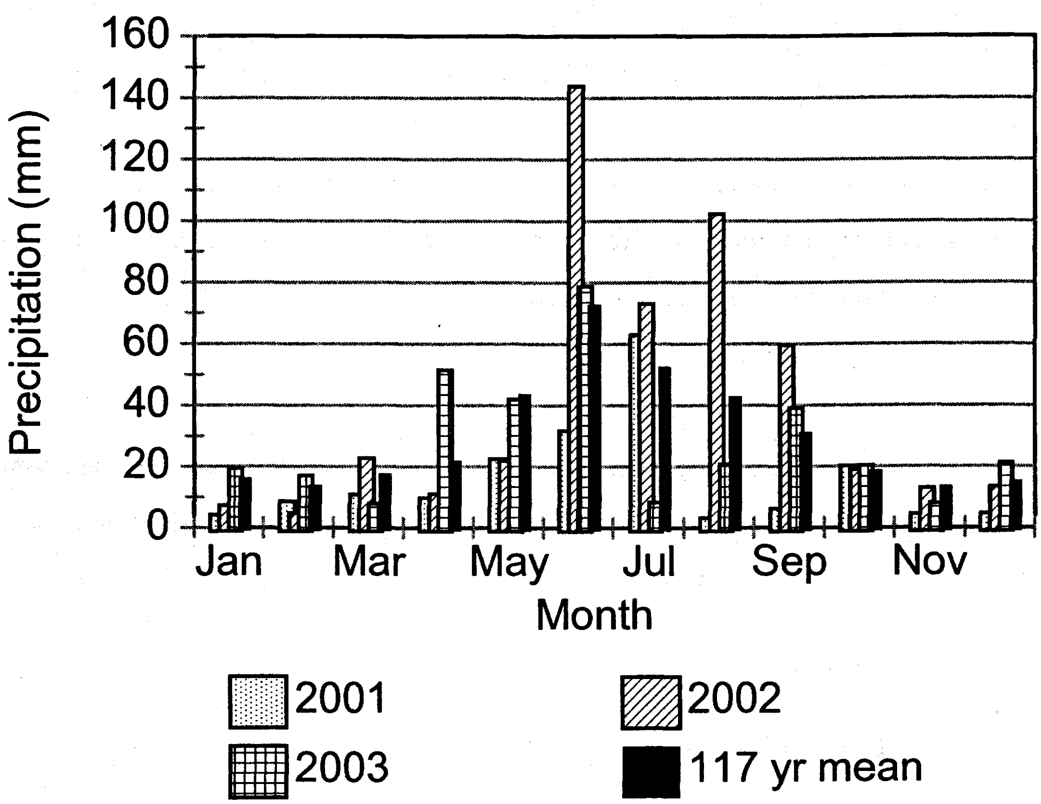

Figure 3.1: Monthly precipitation for 2001, 2002, 2003 and 117 yr average for Swift Current, SK..

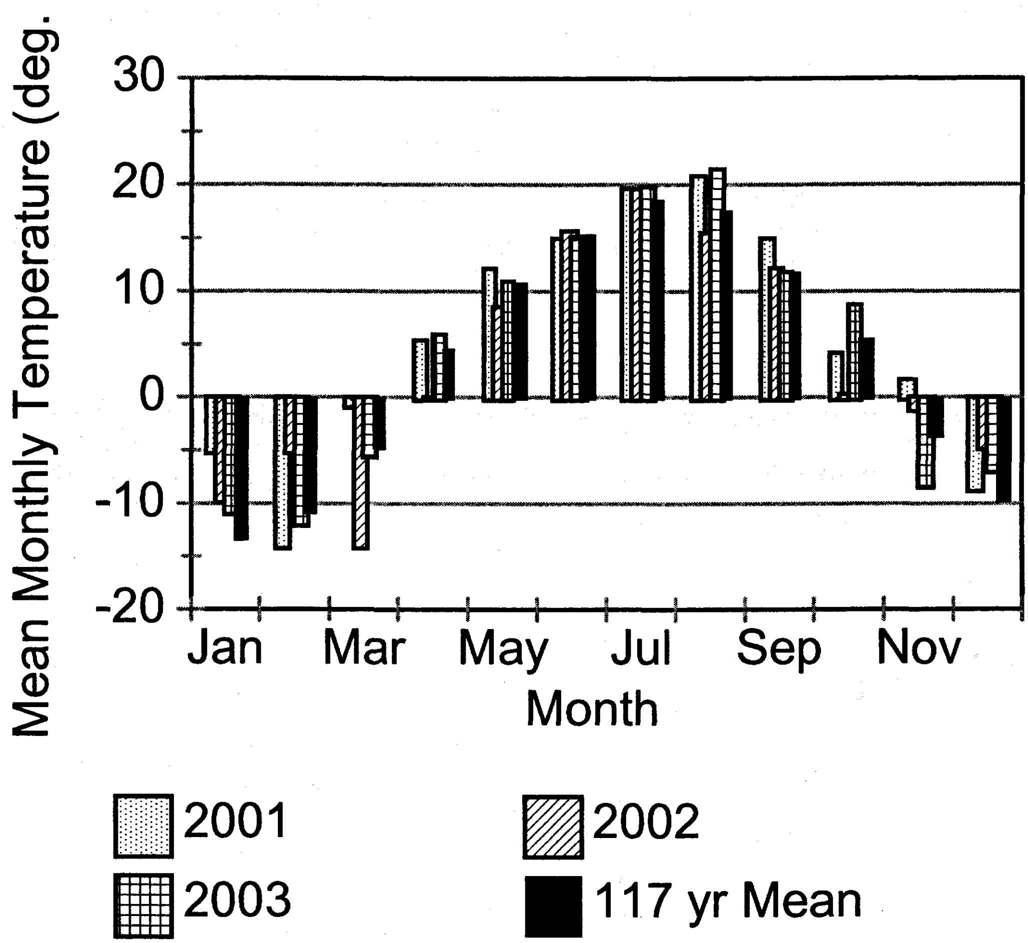

Figure 3.2: Mean monthly temperature for 2001, 2002, 2003 and 117 yr average for Swift Current, SK.

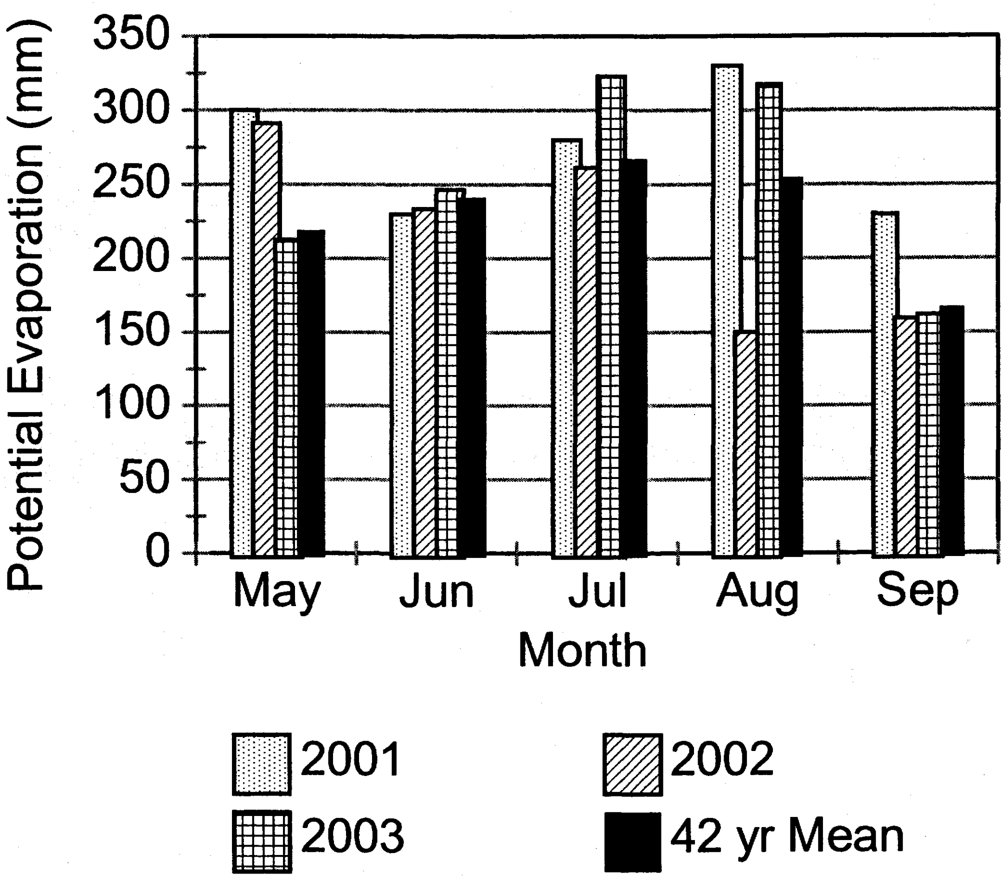

Figure 3.3: Monthly potential "Pan A" evaporation 2001, 2002, 2003 and 42 yr average for Swift Current, SK.

Table 3.1: Means of canopy diameter, primary branches, secondary branching, plant height, plot dry weight and plant dry weight for the factors date of clipping and seed source for 2-year-old plants harvested in 2002 in experiment 1. The fertilizer effect and interactions were not statistically significant ($P > 0.05$) and therefore are not shown.

Factor	Canopy diameter (cm)	Number of primary branches	Number of secondary branches	Plant height (cm)	Dry weight per plot ($g\ m^{-2}$)	Dry weight per plant (g)
Seed Source						
New Mexico	39.1	10	83 b	30.0 a	40	33 a
DU Ecovar™	38.1	9	138 a	27.4 b	46	21 b
SE	4.9	2.1	18	3.2	6.4	3.8
Date of Clipping						
June	27.2 c	------	38 c	16.7 c	14 c	11 c
July	40.5 a	10 a	203 a	39.4 a	37 bc	22 bc
August	45.1 a	11 a	126 b	32.5 b	48 ab	32 ab
September	46.0 a	9 ab	103 b	32.7 b	61 a	37 a
October	35.5 b	6 b	81 b	29.1 b	54 ab	34 ab
November	41.5 a	-----	-----	29.6 b	42 ab	26 ab
SE	8.5	1.5	28.5	5.5	11	6.5

a- c Numbers followed by a different letter in the column within a factor are significantly different ($P < 0.05$) as determined by the Tukey's test.

3.3.2.1.2 Second Year of Harvest 2003

There was a strong seed source by clipping date interaction ($P < 0.05$) for yield, height and canopy diameter in 2003 and both main effects were significant ($P < 0.05$) in 2003. NM plant data had a higher degree of variation for all observations probably due to decreased plant number per plot.

3.3.2.1.2.1 Seed source

Despite the drought in 2003 DU winterfat plants increased canopy diameter, plant height, dry matter yield per plot and dry matter per plant for three year old plants (Table 3.2) over the previous year ($t = |4.3|$, $P < 0.05$) (Table 3.3). Dry matter yield per plant was three times greater ($P < 0.05$) while per plot yields increased four times greater than the previous year (Table 3.3). Canopy diameter increased 1.5 times compared to plants in 2002 ($P < 0.05$) while plants were 22% taller ($P < 0.05$) for 3 year old plants compared to two year plants in 2002 (Table 3.3). Increased plant size, in part is due to a larger plant when growth was initiated in 2003. This result is contrary to reports that winterfat requires more than one year to recover (Romo et al. 1995) from defoliation. The difference may result from a decreased level of defoliation (50% of height in this study vs approximately 90% of height in previous research)which could increase potential carbohydrate reserves. However, these results agree with West and Gasto's (1978) observation of considerable year to year variation in growth.

A large proportion of plants from the NM seed source died in 2003. A Utah seed source was found to withstand temperatures as low as -80° C (Walser et al. 1992), which is below the minimum temperature recorded at Swift Current during the winter of 2002-2003 (Figure 3.2). Assuming NM and Utah winterfat plants share similar temperature tolerances, because they are both southern types, then low temperature is unlikely to be the cause of plant death. Hild and Morgan (1993) noted that mulch will affect crown growth due to decreased evapo-transpiration. A mulch effect from the horticultural matting material combined with record precipitation during 2002 (Figure 3.1 and 3.2)

Table 3.2: Mean canopy diameter, plant height, dry matter (DM) yield per plot, dry matter (DM) yield per plant and number of plants for seed sources, New Mexico (NM) and Ducks Unlimited ecovar™ (DU), as affected by date of clipping at the first site (second year of harvest) in 2003.The seed source by date of clipping interaction was significant ($P < 0.05$). Fertilizer factor data are not shown ($P > 0.05$).

Factor	Canopy Diameter (cm)		Height(cm)		DM yield per plot (g m^{-2})		DM yield per plant (g)		Number of Plants per Plot (g)	
Seed Source	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM
Mean	56.1 a	38.4 b	36 .0	37.7	108 a	22 b	88 a	34 b	10 a	6 b
SE	1.9		0.9		35.0		3.9		0.1	
Date of Clipping										
June	53.3 b	16.3 e	34.0 de	12.4 g	141 b	8 c	71 b	3 c	10 a	6 b
July	53.2 bc	26.0 de	37.0 cde	25.4 f	157 b	32 c	80 ab	16 c	10 a	5 bc
Aug.	65.4 ab	39.6 cd	39.5 ab	34.9 cde	204 ab	27 c	102 ab	18 c	10 a	4 c
Sept.	55.6 b	29.9 de	38.5 bcd	39.2 ab	221 a	6 c	112 a	12 c	10 a	1 cd
Oct.	53.2 bc	74.8 a	33.7 e	67.8 a	155 b	39 c	78 ab	107 a	10 a	1 d
SE	1.2		0.6		30.1		2.7		2.1	

a - d Numbers followed by a different letter in the two columns under factor measured are significantly different ($P < 0.05$) as determined by the Tukey's test.

Table 3.3: Growth parameters (canopy diameter, plant height, dry matter yield per plot and dry matter yield per plant) of DU seed source for first (2 year old plants) and second year (3 year old plants) of harvest in 2002 and 2003 with t-test probabilities.

Growth Parameter	2002 First year of harvest (Exp.1) [a]	2003 First year of harvest (Exp. 2) [b]	Second year of harvest (Exp.1) [c]	t-test comparisons [a] vs [c]	[a] vs [b]	[b] vs [c]
Canopy diameter (cm)	38.5 (7.4)[z]	46.9 (4.3)	56.3 (4.8)	$P < 0.05$	$P < 0.05$	$P < 0.05$
Plant height (cm)	28.6 (4.8)	32.4 (3.2)	36.5 (3.7)	$P < 0.05$	$P < 0.05$	$P < 0.05$
Dry matter yield per plot (g m^{-2})	42.7 (10.0)	121.9 (17.4)	176.4 (21.3)	$P < 0.05$	$P < 0.05$	$P < 0.05$
Dry matter yield per plant (g)	26.9 (5.8)	63.8 (7.7)	88.8 (10.7)	$P < 0.05$	$P < 0.05$	$P < 0.05$

[z] - numbers within parentheses are SE

may have resulted in soil pathogens contributing to the NM plant death in 2003. Harper et al. (1990) and Nelson et al. (1990) concluded soil pathogens and similar wet environmental conditions resulted in a dieback of winterfat in the southwestern United States. However, not all NM plants died and DU ecovar plants suffered little or no death loss. If the forgoing hypothesis is correct, than the survival of DU plants suggests this ecovar may possess some potential disease resistance. Further study is required to definitively test this hypothesis.

The number of primary branches for second year of harvest was greater ($P < 0.05$) for DU plants than NM plants (Table 3.4). Primary and secondary branch diameters of DU plants were thicker than New Mexico plants ($P < 0.05$) in the second year of harvest (Table 3.5). However, NM plants had thicker tertiary branches than DU plants ($P < 0.05$) although the difference was only 2 mm.

3.3.2.1.2.2 Clipping date

Clipping date had an impact on the amount of biomass present in the DU ecovar (Table 3.2). Yield of DU plants (Table 3.2) peaked in September but no significant ($P > 0.05$) increase occurred after July. Plant height and canopy diameter for DU plants peaked in August. Plant height did not increase significantly ($P > 0.05$) after July.

The DU winterfat biomass decreased in fall due to loss of mature seed resulting from wind dispersal. The decrease from September to October was 70 g m^{-2}, an amount less than seed harvested from the same number of plants growing under dryland conditions in another experiment (see Chapter 4). There may have been some leaf senescence but the seed yield data, if similar to what occurred in this experiment, suggests only a minor amount of the decrease to be from leaf senescence. Clipping dates, after two years of harvesting at the same time each year, had not decreased the number of DU plants or their productivity for the date of clipping. Earlier clipped plants had greater increases in yields from 2002 (Table 3.1) to 2003 (Table 3.2) than later clipped plants. The September clip date had a 66% increase while the June clip had an 85% increase from 2002 to 2003 which agrees with observations made by Romo et al. (1995). Biomass yields for plants clipped at 50% of height were 2 to 3 fold greater than total plant biomass removal reported by Romo et al. (1995). Romo et al. (1995) reported their yields for lightly clipped plants were 7 fold greater than those reported for heavily grazed winterfat plants (Clarke and Tisdale 1945). The differences found in yields from Romo et al. (1995) and Clarke and Tisdale (1945) with this study may be in part due to differing environmental conditions, decreased competition for the transplanted plants and/or level of grazing/clipping.

The number of primary branches did not change over the clipping dates (Table 3.4). DU plants had thicker primary and secondary branches at early clipping dates ($P < 0.05$) (Table 3.5). Although NM plants had thicker branches by the October clipping date (Table 3.5) they were not significantly thicker than DU plant branches ($P > 0.05$). For both seed sources, diameter continued to increase until the final clipping date. The

Table 3.4: Means for primary and secondary branching for the factors date of clipping and seed source (New Mexico (NM) and Ducks Unlimited ecovar™ (DU)) for the second experiment, first year of harvest (2003). First experiment second year of harvest (2003) means for number of primary branches are also provided.

	1st Year Harvest		2nd Year Harvest
Factor	Number of primary branches	Number of secondary branches	Number of primary branches
Seed Source			
NM	2 b	15 b	4 b
DU	5 a	57 a	5 a
SE	0.5	6.9	0.7
Date of clipping			
June	3	29 bc	5
July	3	37 ab	5
August	4	53 a	4
September	4	44 ab	4
October	3	31 bc	4
SE	0.9	11.9	1

a-c Numbers followed by a different letter in the column within a factor are significantly different (P<0.05) as determined by the Tukey's test.

Table 3.5: Second year of harvest (2003) for experiment 1 means for primary, secondary and tertiary branch diameters for seed source (New Mexico (NM) and Ducks Unlimited ecovar™ (DU)) and date of clipping factors. The seed source by date of clipping interaction was significant ($P < 0.05$). Fertilizer factor data are not shown ($P > 0.05$).

Factor	Primary branch diameter (cm)		Secondary branch diameter (cm)		Tertiary branch diameter (cm)	
Seed Source	DU	NM	DU	NM	DU	NM
Mean	7.4 a	6.5 d	3.1 a	2.5 b	1.2 b	1.4 a
SE	0.25		0.03		0.04	
Date of Clipping						
June	5.7 cd	2.7 e	2.7 b	1.6 c	1.3 bc	1.2 bc
July	6.1 c	3.9 de	2.8 b	1.9 bc	1.1 cd	1.6 ab
August	6.9 c	5.6 cd	2.8 b	2.8 b	1.0 d	1.2 cd
September	9.0 b	5.1 cde	3.5 a	1.8 bc	1.4 ab	1.0 d
October	9.1 b	14.0 a	3.7 a	4.6 a	1.3 bc	2.0 a
SE	1.6		0.7		0.04	

a - e Numbers followed by a different letter in the two columns within a factor under each diameter are significantly different ($P < 0.05$) as determined by the Tukey's test.

increase was different ($P < 0.05$) between the June to August period and the September to October period for DU plants. NM plants had thicker primary and secondary branches at the end of October than at any other clipping date ($P < 0.05$). October 2003 was warmer than normal (Fig. 3.2) so NM plants appear to exploit advantageous growing conditions late in the growing season.

Plants from the NM seed source increased in individual plant biomass, canopy diameter and plant height until the final clip in October (Table 3.2) but DU plants had greater canopy diameter, biomass production and plant height ($P < 0.05$). Dry matter yield per plot decreased for NM plants because of the fewer plants within the plots.

The NM plants in 2003 (Table 3.2) had decreased growth across all measurements of biomass when compared to yields from the previous year (2002). Their biomass production was greatest at the last clip date ($P < 0.05$) and no decline was seen with DU plants. The number of surviving NM plants in the second year of growth was greater ($P < 0.05$) for June/July clipping date than for September/October clipped plants and less than DU plants ($P < 0.05$).

The clipping date by seed source interaction can be attributed to greater sensitivity to clipping for NM material than for DU material. This increased sensitivity may be due to the immature growth stage of the NM plants, compared to mature and dormant growth stage of the DU plants. Coyne and Cook (1970) found plant vigour for winterfat was dependant on carbohydrate reserves at phenological maturity. The NM plants were not phenologically mature at fall clipping dates, and likely depleting carbohydrate reserves, required for overwinter survival and spring growth, to replace removed biomass. Continued growth of NM seed source suggests that no fall dormancy was initiated by October, which would potentially leave the plants susceptible to damage by low winter temperatures. The continued growth of NM seed source plants may be the result of no sensitivity to light quality changes due to season, or day length and a potentially longer growing season found in New Mexico.

Table 3.6: The seed source by date of clipping interaction (P < 0.05) means for canopy diameter, plant height, dry matter (DM) yield per plot, dry matter (DM) yield per plant and number of plants for seed sources, New Mexico (NM) and Ducks Unlimited ecovar™ (DU), of the second experiment (first year of harvest) in 2003. Fertilizer factor data are not shown (P > 0.05).

Factor	Canopy diameter (cm)		Height (cm)		DM per plot ($g\ m^{-2}$)		DM per plant (g)		Number of Plants per Plot	
Seed Source	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM
Date of Clipping										
June	37.4 bc	5.4 e	23.6 de	8.2 f	43 c	<1 c	25 c	<1 c	9 a	1 c
July	46.6 ab	20.8 cde	32.6 bc	24.3 cde	105 b	3 c	53 b	4 c	10 a	2 bc
Aug.	49.5 a	29.5 cd	35.3 ab	28.4 cd	150 ab	8 c	79 ab	9 c	10 a	4 bc
Sept.	53.7 a	17.2 e	36.6 a	19.3 e	174 a	6 c	90 a	8 c	10 a	4bc
Oct.	48.6 a	20.1 de	33.7 abc	20.8 e	152 ab	5 c	80 a	5 c	9 a	4 b
SE	2.9		1.5		13		5.9		0.6	

a - e Numbers followed by a different letter in the two columns under a measured characteristic are significantly different (P<0.05) as determined by the Tukey's test.

3.3.2.2 Experiment 2

3.3.2.2.1 First Year of Harvest 2003

3.3.2.2.1.1 Seed Source

Despite the drought in 2003 DU winterfat plants had greater ($P < 0.05$) canopy diameter, plant height, dry matter per plot and dry matter per plant than two year old plants in 2002 (Table 3.3). The increase in productivity may be related to the plants adaptation to dry growing conditions (Love and West 1972; Moore et al. 1971; Moore et al. 1972) or utilization soil moisture from the previous year as observed by Wiengand et al. (2004) for South African plants. Peak dry matter yield per plot was three times greater ($P < 0.05$) for experiment 2 plants in 2003 than plants for experiment 1 in 2002, but a third less ($P < 0.05$) than plants for experiment 1 in 2003. Canopy diameter was 1.2 times greater ($P < 0.05$) for experiment 2 plants in 2003 than plants for experiment 1 in 2002, when both had 2 years growth. Plant height was 1.1 times greater ($P < 0.05$) for experiment 2 plants in 2003 than plants for experiment 1 in 2002. This result agrees with West and Gasto's (1978) observation of considerable year to year variation in growth. The 2 year old plants in experiment 2 were smaller than 3 year old plants in experiment 1 ($P < 0.05$) (Table 3.3) as expected with experiment 1 plants having an additional year of growth.

Number of branches for first year of harvest, in 2003, was greater ($P < 0.05$) for DU plants (Table 3.4). The number of primary branches did not change over the growing season. Secondary branching did increase ($P < 0.05$) until August and then declined possibly due to breakage as the plants dried down.

3.3.2.2.2.1 Clipping Date

Clipping date had an impact ($P < 0.05$) on biomass per plot, canopy diameter and height for the DU ecovar™ in 2003 (Table 3.6). As in experiment 1, yield per plot and per plant of DU plants, plant height and canopy diameter peaked in September. The canopy diameter had no significant ($P > 0.05$) increase from July to October. The plant height and dry matter yields had no significant ($P > 0.05$) increase from August until October. This suggests that growth stops during the July to August period. The biomass decrease in fall (P > 0.05) was due to loss of seed resulting from dispersal resulting from high winds. However, this decrease was not significant. The decrease from September to October was 22 g m^{-2}, an amount less than seed harvested from the same number of plants growing under dryland conditions (see Chapter 4). There may have been some leaf senescence but the seed yield data, if similar to what occurred in this experiment, suggests only a minor amount of the decrease to be from leaf senescence.

The height and canopy diameter of NM plants peaked in August, a month earlier than the DU plants. There were no detectable differences (P > 0.05) in dry matter yield per plot or per plant for NM plants because they were low. Canopy diameter, dry matter yield and plant numbers were less (P < 0.05) than observed for DU plants at all clipping dates. Only the NM July and August plant heights approached values similar to DU plants. This was in part due to plant death during the winter of 2002-2003. The plant death likely occurred for the same reasons hypothesized for experiment 1 despite younger plants, which would indicate that the cause was not related to age.

3.3.2.3 General Results and Discussion for Canopy Structure and Biomass

Increased productivity during the hot dry year of 2003 (Table 3.3) indicates the potential winterfat may have as a drought-adapted forage. Possible reasons for this increased productivity include greater root development for the three year old plants, the previous year's growing conditions, and reduced loss of soil moisture from soil surface due to weed barrier fabric. Schwinning et al. (2003) found that winterfat can extract soil water from a depth of 20 cm or more. Wiengand et al. (2004) found that plants growing in the semiarid region of South Africa exhibited a residual response to previous years environmental conditions. The potential residual soil water could have been accessed by the deep growing roots of the winterfat plants.

For the first year of harvest in both experiment 1 and 2, current and previous years growth of branches would have been clipped. The leaf material and a portion of te secondary branches would be current year growth. Only current year of growth material would have been clipped in the experiment 1 with three year old plants (2003) . In 2002 (experiment 1) NM was clipped at 15.0 cm and DU at 13.7 cm. Whereas for 2003, NM was clipped at18.9 cm and DU at 18.0 cm.

The effect of clipping observed in these experiments was uniformly imposed within a year but such uniformity would not necessarily occur in a grazing situation. In addition to varying harvesting heights due to the animal selection there would also be variation in trampling, defecation, plant selection and saliva impacts, all of which were absent in this study. Therefore the responses of the plants could be quite different from what was observed and the responses to these animal-plant interaction factors need to be investigated.

In addition to the uniform defoliation the growing environment was controlled with the elimination of competition from other plant species. Competition from other plant species would influence biomass production. Schellenberg (2002) observed a significant decrease in seed production after the removal of the weed-barrier fabric.

The use of transplants as replacement in the first year of clipping for both sites may have decreased possible biomass production estimates due to transplants expending energy to establish and adjust to the environment. Survival due to clipping appeared unaffected in DU plants. If overestimation of the presence/absence of plants did occur it may have been with death of NM plants, again due to energy expended to adjust to the environment.

Estimation of biomass using 50% of height does not translate to 50% of biomass produced. To determine the amount of biomass removed entire plants should have been clipped in the following fashion: remove 50% by height then clip the remaining and calculate the amount removed by 50% of height. Therefore the amount removed by clipping to 50% of height may have been less than 50% of production although visual observation in 2003 would suggest close to 50% of biomass was removed.

New Mexico plants from experiment 1 were taller ($P < 0.05$) than DU plants (Tables 3.1 and 3.2) but only exceeded 38 cm in September and October 2003 (Table 3.2). This suggests that both sources would fit the dwarf growth form typical of xeric valley sites. This classification approach does not seem to take into account winterfat growing in anthropogenically-manipulated sites, as in these experiments. One might expect growth form, specifically height, to be altered by conditions found at new sites not previously available through natural dispersal.

Death of the NM plants (Table 3.2 and 3.6) in 2003 appeared unrelated to age because both two and three year old plants were similarly affected. Clipping in the fall reduced survival of the NM plants (Table 3.2) compared to summer clipped plants. Perhaps this response was due to reduced carbohydrate reserves for over wintering and spring growth in fall-clipped NM plants.

Fertilizer failed to provide any increased productivity. In 2003, DU plants exhibited a response to fertilizer in canopy diameter and height (Table A2) but this did not translate into increased production. This may have been in part due to the potential leaching of the fertilizer below the roots in 2002. In 2003, it is possible that insufficient nutrients made it to the 20 cm depth for nutrient uptake (Schwinning et al. 2003) or the 50 cm region of active root growth noted for drought conditions (Fernandez and Caldwell 1975). The timing of fertilizer application may also be a contributing factor. Majerus (2003) applied fertilizer in fall as a standard protocol with no results reported. In this study the fertilizer was applied in spring. In addition the weed barrier fabric increased soil water content and increased the soil temperature which may have increased microbial activity in the soil (Brady 1974). Increased microbial activity may have resulted in the fertilizer being utilized by microbes prior to its utilization by the plants. Native plants utilize soil nutrients over longer periods of time as opposed to a rapid growth response exhibited by many colonizer species (Blonski et al. 2004; Grime 2002) so a fertilizer response should not be expected for such species.

3.3.3 Stage of Growth

3.3.3.1 Experiment 1

3.3.3.1.1 First Year of Harvest 2002

Under the climatic conditions encountered in 2001 the DU seed source initiated growth earlier than NM seed source. The DU plants also reached phenological maturity while NM plants were vegetative (Table 3.7) throughout the season.

3.3.3.1.2 Second Year of Harvest 2003

The same pattern was found for 2003, when DU plants reached phenological maturity at both experiments (Table 3.8). New Mexico seed source progressed to the bud stage under the hot dry weather conditions encountered in 2003.

3.3.3.2 Experiment 2

3.3.3.1.1 First Year of Harvest 2003

DU plants reached phenological maturity in 2003 for experiment 2 as they did for the first harvest of experiment 1 (Table 3.8). New Mexico seed source progressed to the bud stage under the hot dry weather conditions encountered in 2003 but progression was not observed in plants clipped later. The progression may have been related to observation error or an affect associated with clipping. Further research is required to verify the observed phenological advance and regression of NM.

3.3.3.3 General Results and Discussion for Stage of Growth

Observations from both experiments suggest a higher base temperature requirement for NM growth. There are reports that germination temperature requirements are higher for NM seeds compared to Saskatchewan seeds (Thygersen et al. 2002; Schellenberg 2003). Further research is required to differentiate optimum growth temperature from other environmental factors that influence phenological progression, including bud development, flowering, seed production and seed dispersal.

Fertilizer had no detectable affect on phenological development in either experiment (Table A3).

3.3.4 Leaf Stem Growth

Mean leaf width and length appear to be similar between two and three year old plants (Table 3.9). Leaves within 1.5 cm of the tip stay fairly uniform throughout the growing season. The middle and bottom leaves decline in width and length as the growing season progresses. This decline in size may be interpreted as a shift incarbon allocation from leaf production to seed production and/or increasing carbohydrate root reserves for future development. Coyne and Cook (1970) noted root reserves are maximized at phenological maturity which occurs in fall for some plants on the

Table 3.7: Stage of growth as assessed on date of clipping for New Mexico and DU seed sources in the first year of harvest, 2002, Experiment 1. The seed source by date of clipping interaction was significant ($P < 0.05$). Fertilizer factor data not shown due to lack of effect ($P > 0.05$) .

Seed Source	DU		NM	
Date of Clipping				
June	Bud/flower	d	Vegetative	e
July	Flower	c	Vegetative	e
August	Flower/seed	c	Vegetative	e
September	Seed	b	Vegetative	e
October	Seed	b	Vegetative	e
November	50% seed loss	a	Vegetative	e
SE		1.4		

a - e Stages followed by a different letter in the two columns are significantly different ($P < 0.05$) as determined by the Tukey's test.

Table 3.8: Stage of growth for first (Experiment 2) and second year (Experiment 1) of harvest of winterfat plants in 2003. The seed source by date of clipping interaction was significant ($P < 0.05$) thus means for seed source by clipping date are shown. Fertilizer factor data not shown due to lack of effect ($P > 0.05$).

Factor	1st Year of harvest Experiment 2				2nd Year of harvest Experiment 1			
Seed Source	DU		NM		DU		NM	
Date of Seeding								
June	Bud	e	Vegetative	ef	Bud/Flower	de	Vegetative	f
July	Bud/Flower	d	Bud	efg	Flower/Seed	c	Vegetative	e
August	Bud/flower /seed	c	Bud/Seed	v	Flower/seed	bc	Bud/Seed	d
September	Seed	b	Vegetative	g	Seed	ab	Bud	ef
October	50% Seed loss	a	Vegetative	g	50% Seed loss	a	Bud	ef
SE			0.3				1.4	

a - g Within an experiment stages followed by a different letter in the two columns are significantly different ($P < 0.05$) as determined by the Tukey's test.

Table 3.9: Leaf width, leaf length and leaf/stem weight ratio for plants with 3 (Experiment 1) and 2 (Experiment 2) years growth for DU seed source. Material was harvested in 2003. Fertilizer factor data not shown due to lack of effect (P > 0.05). Insufficient sample prevented inclusion of New Mexico material.

	Leaf dimensions (mm)						Leaf to Stem weight ratio
Three Years Growth	Top width	Middle width	Bottom width	Top length	Middle Length	Bottom Length	
Date of Clipping							
June	1	3 a	4 a	14	30 a	37 a	2.6 a
July	1	2 ab	4 ab	11	23 b	22 b	3.0 a
Aug	1	2 ab	3 b	10	19 b	26 ab	2.9 a
Sept	1	2 b	3 b	11	18 b	21 b	2.1 ab
Oct	1	1 c	1 c	9	10 c	12 c	2.0 c
SE	0.4	0.6	1	3.2	6.5	8.3	0.8
Two Years Growth							
Date of Clipping							
June	1.5	3 a	4 a	13	27 a	33 a	2.9
July	1.2	2 b	4 ab	12	24 ab	28 ab	3.3
Aug	1.2	2 b	2 c	11	17 b	20 b	2.5
Sept	1.1	2 b	3 bc	9	19 b	23 b	3.3
Oct	1.1	2 b	3 bc	8	19 ab	17 b	2.6
SE	4	0.7	0.9	0.4	6.2	7.8	0.7

a - c Numbers followed by a different letter in the column are statistically significant (P < 0.05) as determined by Tukey's test.

Canadian prairies. Later in the season, there was an increase in the stem weight resulting in lower leaf to stem weight ratio. As a result of decreased leaf size the grazing animal would be presented with forage material with a higher proportion of twig, which in turn, may impact nutritive quality. This increase in stem would suggest greater fibre concentration in the forage which would affect ruminant digestion (Deinum 1973).

3.4 Conclusions

NM and DU plants differed in phenological progress towards maturity and plant growth characteristics. During the first harvest season for plants established in 2001 NM plants were taller with greater individual plant dry matter. However DU plants produced more biomass on a per plot basis due to greater number of surviving plants. In the second year, 2003, NM plants demonstrated death loss which appeared to be a sensitivity to time of clipping. This sensitivity may be attributed to decreased vigour due to lower carbohydrate reserves. In failing to complete their phenological cycle NM plants likely failed to reach the maximum potential for carbohydrate root reserves required for over wintering and disease resistance. The failure of the NM plants to complete their life cycle was likely due to lack of triggers, such as temperature changes that are found in its normal environment. Carbohydrate root reserves may have been further depleted in efforts to replace clipped material. The results suggest a potential within the DU genetic material for increased persistence.

Defoliation of DU plants at 50% of height for the 2 years of this study suggested no deleterious effect at any clipping date. This contrasts to Romo et al.'s (1995) observations that plants defoliated to a height of 5 cm (approximately 90% of height) required extended recovery periods.

Both plant types increased forage productivity during the drought conditions of 2003 which further demonstrates their forage potential during periods when grass productivity is low. This drought tolerance may be associated with the ability of winterfat to draw moisture from depth, decreased evaporation (Schwinning et al. 2003) and lower physiological activity (Moore et al. 1972) or the favourable conditions of the experimental setup.

Fertilizer, as applied, had no effect on growth, forage yield, branching or survival. The lack of fertility response has been reported for stress tolerant plants (Grime 2002) and native prairie species (Blonski et al. 2004) in which utilization of soil nutrients is drawn out over time. This lack of fertility response was also noted for winterfat by Goodman (1973).

DU winterfat has the greater potential for growth in the Canadian prairie environment but NM material has some traits, such as greater plant growth, which may have some advantages if plant breeding is initiated for this species.

CHAPTER 4

SEED PRODUCTION POTENTIAL AS AFFECTED BY SEED SOURCE, FERTILIZATION AND IRRIGATION

4.1 Introduction

The semi-shrub winterfat, *Krascheninnikovia lanata* (Pursh) A.D.J. Meeuse & Smit, is known for its high nutritive value as a winter forage (Sampson 1924; Smoliak and Bezeau 1967; Abouguendia 1998).Winterfat is a shrub found from Mexico (Springfield 1974) to Canada (Great Plains Flora Association 1986) as far north as Sheep Mountain in the Yukon (Hoefs et al. 1975), but not in Alaska (Vetter 2000).

If this species is to be utilized in livestock grazing systems then more information about seed production is required to ensure adequate seed availability and to reduce seed costs. Winterfat seed has a short shelf-life of less than three years if stored at ambient temperatures (Springfield 1972) and a 90% reduction in viability has been observed by the author within a year. Therefore a constantly renewed commercial seed supply will be required.

Majerus (2003) concluded that winterfat exhibited good potential for commercial production using standard seed production methods. West and Gasto (1978) noted that considerable year-to-year variability in winterfat seed production can occur with no seed produced some years. One possible approach to ensure higher and more consistent production would be to manipulate the growing environment. Ogle et al. (2003) noted that winterfat transplants result in the most satisfactory seed orchards. They also indicated that transplanting winterfat into a weed-barrier fabric can improve plant establishment, seed production, weed control and moisture conservation. Two to three years of growth were required by winterfat before commercial seed production occurred (Ogle et al. 2003). Standard seed production methods for winterfat seed production in Montana included supplemental irrigation water applied prior to flowering, at post-anthesis and at post-harvest prior to freeze up (Majerus 2003). In addition to water, a late fall application of 45 kg ha^{-1} nitrogen and 22 kg ha^{-1} phosphorous was done as standard protocol (Majerus 2003). Stevens et al. (1996) indicated that no fertilization was required for winterfat seed production in Utah. Stevens et al. (1996) also noted that irrigation should be considered supplemental to natural precipitationin the event of drought but the amount of irrigation would be less than that used for agronomic species. Schellenberg (2002) increased soil moisture and seed production by limiting soil moisture loss using weed-barrier landscape fabric as a soil mulch. Reidl et al. (1964) reported increased biomass production when N, P and K fertilizers were added to pots containing winterfat seedlings. These conflicting reports regarding requirements of fertilizer and irrigation need to be resolved for the Canadian prairie environment.

To date, winterfat seed production in the Canadian prairies has been mainly for research purposes and the best agronomic practices for commercial production have not been established. Seed production potential differences between northern and southern winterfat seed sources are not known although Schellenberg (2002) noted that the New Mexico seed source material was capable of overwintering in Saskatchewan.

Winterfat seed can be harvested from wild plants throughout its range with appropriate permission and this is the main source of seed, with New Mexico seed being the most readily available (Wind River Seeds, personal communication). In the United States, through USDA-NRCS, there are currently three germplasms or seed sources available: Hatch from Los Lunas Plant Materials Centre, New Mexico; Northern cold desert germplasm released by Aberdeen Plant Materials Centre and Idaho Agricultural Experiment Station; and Open range germplasm released by Bridger, Montana Plant Materials Center (Ogle et al. 2003). At the time of initiation of this work, only Hatch was available.

In co-operation with the Semiarid Prairie Agricultural Research Centre (SPARC) - AAFC, Ducks Unlimited Canada (DU) have developed a winterfat ecovar™ or ecological variety of Saskatchewan source germplasm for western Canada. The ecological variety is intended to have a greater genetic diversity than a cultivar. The winterfat ecovar is made up of seed collected from 16 sites across southern Saskatchewan. The resulting plants were grown in a field plot nursery at SPARC. The seed harvested from the SPARC nursery was then bulked and released for seed increase as the winterfat ecovar™. There was no selection imposed for agronomic characteristics such as seed production, grazing tolerance or nutritional qualities.

The objectives of this study were 1) to determine if growth and seed production characteristics differ between a southern winterfat plant type from New Mexico (NM) and a northern plant type from Saskatchewan (DU ecovar™) when provided fertilizer and supplemental irrigation water and 2) to determine if management of fertilizer and irrigation can reduce annual variation in seed production.

4.2 Materials and Methods

Split plot experiments with four replicates (Figure A2) were established at the Semiarid Prairie Agricultural Research Centre (SPARC), Swift Current, Saskatchewan (50° 17′ N, 107° 41′ W; elevation 825 m) on an alluvial Rego Chernozem (clay to clay loam) (Ayres et al. 1985). The split plot design was chosen due to the physical constraints of the irrigation system. The main plot (Figure A2) factor was irrigation with Rainbird fine drop sprinklers of 5 (± 1.3) cm of water in August (seed set), October (post harvest prior to freeze up) or no irrigation. The subplot factors (Figure A2) were 1) transplants grown from seed of New Mexico wild plants (NM; seed supplied by Wind River Seeds) and of Saskatchewan nursery plants (DU; Ducks Unlimited Canada ecovar™); 2) 100 kg ha^{-1}N and 50 kg ha^{-1} P as P_2O_5 fertilizer or no fertilizer. The subplots (site 1) were10 transplanted plants (NM or DU) spaced 0.5 m apart within the subplot (Figure A2) and separated by 1 m (Figure A2) in 2001. The weed barrier fabric (supplied by the Professional Gardener Co. Ltd., Calgary, AB.) was selected for conservation of moisture and to restrict the presence of weeds. Adjacent to the first site, the second experiment (site 2) was established in 2002, with the same layout. Fertilizer was broadcast in appropriate subplots just prior to irrigation including the no irrigation main plot. Fertilizer rates for N and P were similar to those recommended for cultivated

Saskatchewan forage crops (Murrell 1992). Soil N and P availability were determined by automated hydrazine reduction extraction and automated acid molybdate/ascorbic acid extraction (Winkleman 1998) of soil samples taken prior to addition of fertilizer.

Replacement of dead plants only occurred during the year following initial transplanting. Transplants used for replacement were from the same seed batch and approximately the same age having been maintained in the greenhouse for this purpose.

Daily mean temperatures, precipitation and potential evaporation (US Weather Bureau Class A pan) were obtained from the SPARC weather station approximately 3 km away. In addition, soil moisture content for the top 15 cm was determined by time domain reflectrometer (TDR; Soil Moisture Trase Systems) with 15 cm probes. Dates for soil moisture sampling were 19 June, 17 July, 14 August and 8 October in 2002. For site 2, the dates for soil moisture sampling were 12 July, 29 July, 1 August, 19 August, 29 August and 26 September in 2002. In 2003, the dates for soil moisture sampling were 10 May, 27 May, 25 June, 12 July, 1 August, 14 August, 29 August, 10 September and 26 September for site 1. For site 2, the dates for soil moisture sampling were 19 June, 17 July, 14 August, 8 October and 14 October in 2003. A laser targeted infrared thermometer (Oaktron InfraPro model 35629-20) was used to obtain basal plant temperatures at the base of one randomly selected plant per plot from 10 a.m. until 2 p.m. on the day of measurement. Basal plant temperatures were obtained 25 June, 12 July, 29 July, 14 August, 29 August and 26 September for site 1. For site 2, in 2002, basal plant temperatures were obtained 16 July, 29 July, 14 August, 29 August and 10 September. In 2003, site 1 basal temperatures were obtained on 19 June, 17 July and 14 August and 19 June. Basal temperatures were obtained on 17 July and 14 August for site 2 in 2003.

Plant height , canopy cover and basal cover for a 0.25 m^2 (expressed as per cent of area covered by plant) for three randomly selected plants per plot were determined in the early part of each month from June to September. Seeds were stripped by hand, as recommended by Schellenberg (2002) to avoid excessive damage to the plants, for each plant weighed and recorded then bulked per plot and weighed. Seed harvest occurred from the early part of September to the first 2 weeks of October for both years. Ripe seed was collected every 2 weeks during this period. Seed was cleaned by running through a barley de-awner to break up twigs and then over a clipper scalper cleaner to remove twigs, leaves and empty bracts.

Data were tested for fit to normal distribution using the Shapiro-Wilk test (SAS 1999). All data were statistically analysed, main plot treatments, subplot treatments and their interactions, using ANOVA for individual years with Proc GLM (SAS Institute, Inc. 1999). Standard error (SE) was calculated (Steel and Torrie 1980). The stage of growth was rated with a numeric score (Table A1), analyzed using ANOVA for individual years using Proc GLM (SAS Institute, Inc. 1999) and the mean result converted back to mean growth stage. When a factor was significant, $P < 0.05$, Tukey's test was used for mean separation (Steel and Torrie 1980). Due to the failure of NM winterfat plants to set seed, the seed source factor was dropped from the ANOVA for seed production and stage of growth.

4.3 Results and Discussion

The Shapiro-Wilk goodness of fit test indicated the data were normally distributed. Interactions for irrigation and fertilizer were not significant ($P > 0.05$).

4.3.1 Production

New Mexico plants failure to set seed may be attributed to the shorter growing season in Saskatchewan as well as lower temperatures than encountered in New Mexico during the flowering and seed set stages (see chapter 3 discussion). Larcher (1995) indicated that the progression through phenological development, from vegetative growth to flushing and flowering, is greatly influenced by temperature.

In 2002, for site 1 plants (2 years growth), irrigation water as well as fertilization had no effect ($P > 0.05$) (Table A4) on plant height, canopy cover and seed yield. At the August date no irrigation plots were one phenological stage further advanced than irrigated plants, but the difference disappeared by the September sampling date. There was no effect of irrigation on seed yield. The lack of irrigation effect was probably due to the higher than normal rainfall in 2002, which would eliminate water as the primary limiting factor for seed production. The lack of fertilization effect can possibly be explained in part by the excess water leaching the fertilizer beyond the root zone before root uptake could occur. In a normal year one might expect irrigation to increase growth and seed production but in 2002 higher than normal precipitation (Fig. 3.1) may have masked any irrigation effect. Branching (Table A5) did not occur prior to the July assessment. The 16 July assessment found only a single primary branch with few plants exhibiting secondary branching. By the August date, tertiary branches had developed. This is surmised from the fact that flowers only occur on tertiary branches and flowering had commenced by the 19 August assessment. By 19 August the plants had developed 10 (SE = 4.1) primary branches on average with 112 (SE = 5.2) secondary branches. Plant heights varied with the plant measured. On average, the plants obtained a height of 33 (SE = 5.0) cm with a canopy diameter of 40 cm (SE = 8.5) by August. The seed harvested on 20 September, 7 and 8 October totalled a mean of 2.7 g m^{-2} (SE = 0.4). This low seed yield may have resulted due to delayed annual seed production development. Ogle et al. (2003) noted seed production may not occur until the 2^{nd} or 3^{rd} year of growth. Data from 2003 site 2 (Table 4.1) indicate seed production can occur in Saskatchewan in the second year of growth.

In the fall of 2002 both sites had the full complement of plants but New Mexico plants experienced a death loss in both study sites by the spring of 2003. The winter of 2001-2002 was warmer than 2002-2003 but winterfat from southwestern US reportedly can withstand -80° C during the winter (Walser et al. 1992), which is well below temperatures recorded at Swift Current for the winter of 2002-2003 (Figure 3.2). Hild and Morgan (1993) noted that mulch will decrease crown growth with a decrease in evapo-transpiration. This decrease in evapo-transpiration combined with record precipitation in 2002 (Figure 3.1 and 3.2) likely resulted in an increase in soil pathogens. Harper et al. (1990) and Nelson et al. (1990) concluded that wet growing conditions resulted in death of winterfat in the southwestern United States. DU ecovar plants were relatively unaffected which might indicate potential disease resistance in the DU seed source if the soil pathogen hypothesis is valid.

In 2003, plants with three years of growth (site 1) had similar canopy and basal cover among fertilization and irrigation treatments. Mean canopy cover was 75.0% (SE = 19.5) while mean basal cover was 50.9% (SE = 22.5). Mean plant height, also measured on 4 September 2003, was likewise unaffected by water or fertilizer application and was 41.3 cm (SE = 5.1), a 30% increase over the previous year.

Seed harvest for 2003 (site 1) was started on 4 September and was completed on 1-2 October. Seed yield per plot was 45 times greater than the previous year and roughly equivalent to the first harvest year yield for site 2 (Table 4.1). Although not statistically different ($P > 0.05$) irrigation treatments tended to increase seed yield by 25 to 29% over the control. The October fertilizer application treatment and control yielded more seed ($P < 0.05$) per plot than the August fertilizer application for three year old plants (site 1). The negative impact of the August fertilization may be attributed to a delay in seed fill or seed set which resulted in an increased number of aborted seeds. Nitrogen fertilizer can be expected to increase seed production and speed up phenological development (Christian 1987) for many introduced forage grasses which tend to be more aggressive colonizing species. Nitrogen fertilizer can have complex and variable effects (Wilson 1982) depending on forage species (ie. grass vs legume). Petersen and Ueckert (2005) found neither irrigation nor fertilizer had an effect on vegetative growth, seed yield or mortality of *Atriplex canescens* (Pursh) Nutt., which is another chenopod desert shrub. Nitrogen fertilizer is known to delay plant development in annual monocot crops (Russell 1961). Similar delays in phenological development were found with application of manure in tame pasture and native range and native range had slower N uptake (Blonski et al. 2004). The August application of fertilizer for 2003 delayed phenological development (Table 4.2). Unfortunately this also was the period of the highest temperatures and a phenological delay would have disrupted seed maturation. There was no difference among fertilizer and irrigation treatments ($P > 0.05$) or DU plant survival, with 80% survival. Fertilizer application appears to have had a negative impact on seed production (Table 4.1).

Table 4.1: Seed yields per plot and per plant for a first and second year of harvest of DU plants in 2003. Main plot was irrigation with fertilizer as subplots. No New Mexico plants developed beyond vegetative state and therefore results are for DU seed source only.

	First year harvest (Site 2)		Second year harvest (Site 1)	
Factor	Per Plot (g m^{-2})	Per Plant (g)	Per Plot (g m^{-2})	Per Plant (g)
Irrigation				
August	148.5	145	127.7	137
October	115.6	113	124.7	137
None	115.4	107	97.1	111
SE	10.6	17.8	8.6	16.4
Fertilizer				
August Application	135.6	108	86.4 b	102 b
October Application	127	122	126.2 a	135 ab
No Application	116.9	135	136.9 a	148 a
SE	10.6	17.8	8.6	16.4

a - b Numbers for a factor followed by a different letter within a column are significantly different ($P < 0.05$) as determined by the Tukey's test.

Table 4.2: Stage of growth for first and second year of harvest on a given date for Ducks Unlimited plants in 2003. The main plot was irrigation with fertilizer as subplots. No New Mexico plants developed beyond vegetative state and therefore results reflect the phenological stages in DU material only.

	First year of harvest (Site 2)								Second year of harvest (Site 1)							
Factor	**Fertilizer**				**Irrigation**				**Fertilizer**				**Irrigation**			
	Aug	Oct	None	SE	Aug	Oct	None	SE	Aug	Oct	None	SE	Aug	Oct	None	SE
Date																
6 June	B/F	B/F	B/F	0.2	B/F	B/F	B/F	0.2	B a	B/F b	B/F b	0.2	B/F	B/F	B/F	0.2
16 July	B/F/S	B/F/S	B/F/S	0.3	B/F/S	B/F/S	B/F/S	0.3	F	B/F/S	B/F/S	0.4	B/F/S	B/F/S	B/F/S	0.4
11 Aug	F / S	F / S	F / S	0.2	B/F/S	F / S	F / S	0.2	F / S	F / S	F / S	0.3	F / S	F / S	F / S	0.3
19 Sept	F / S	F / S	F / S	0.1	F / S	F / S	F / S	0.1	F / S	F / S	F / S	0.4	F / S	F / S	F / S	0.4

B - Bud, F - Flower, S - Seed, B/F/S - Bud/Flower/Seed, F/S - Flower/Seed

a-b Within the row stages for factors followed by a different letter are significantly different ($P < 0.05$) as determined by the Tukey's test. (Numerical stage of growth scores are listed in Table A1)

For site 2 (first year of harvest) in 2003, fertilizer failed to produce any effect ($P > 0.05$) on any measured factor.

Schellenberg (2002) and Ogle et al. (2003) indicated the weed barrier fabric will increase soil water content. The black weed barrier fabric would also be expected to increase the soil temperature. The increased soil moisture and increased surface temperature may have increased microbial activity in the soil (Brady 1974). Increased microbial activity may have promoted the fertilizer utilization by soil microbes prior to utilization by winterfat.

For site 2, plant height, canopy and basal cover (Table 4.3) were unaffected by irrigation treatments. Ducks Unlimited plants were larger ($P < 0.05$) and exhibited denser canopies and greater basal cover than New Mexico plants.

Seed yield for 2 year old DU plants harvested for the first time in 2003 (site 2) (Table 4.1) was not affected by irrigation or fertilizer ($P > 0.05$). The seed yield was approximately 49 times greater than the site 1 first year harvest in 2002 but very similar to site 1 second year harvest results in 2003 (table 4.1), which suggests that seed production is favoured under a hot dry environment and disadvantaged by a cool wet environment. Survival of DU plants averaged 90% per plot, compared to 20% for NM. The August irrigation tended to produce a 23% increase in yield per plot but this was not statistically significant ($P > 0.05$). Fertilization, while not a significant factor ($P > 0.05$), tended to decrease seed yield by 6 to 15%, likely for the same reasons stated above for the site 1 second year harvest in 2003 (Table 4.2). Grime (2002) suggested that stress tolerant species such as winterfat often increase their root mass for slow release of the nutrients at a later date. Weingand et al.'s (2004) results from South Africa suggest that some plant species exhibit a delay response to additional precipitation. If this delay in fertilizer and irrigation effect occurred for site 1 then perhaps the delay to realize benefits from fertilizer effect may be greater than 2 years.

The higher seed yield in for 2003 compared to 2002 may be due to the increased temperatures. Soil moisture was above the permanent wilting point for agronomic species. Most of the growth for desert plants occurs in a more xeric climate than is

Table 4.3: Means of plant height, percent canopy and basal cover for first year of harvest for 0.25 m^2 in 2003. Interactions and fertilizer are not significant ($P > 0.05$) and therefore are not shown. Main Plot (irrigation) and subplot factors (seed source) provided.

Factor	Plant height (cm)	Canopy Cover (%)	Basal Cover (%)
Seed Source			
New Mexico	28.9 b	26.3 b	16.5 b
Ducks Unlimited	41.6 a	73.2 a	52.2 a
SE	3.4	7	6.7
Irrigation			
August	35.6	51.3	34.4
October	34.9	45.6	37.6
None	35.3	52.3	31.1
SE	3	6	8.1

a- b Numbers followed by a different letter for a factor in a column are significantly different ($P < 0.05$) as determined by the Tukey's test.

suitable for most agronomic species. The permanent wilting point for desert species is well below that of agronomic species (Love and West 1972). Soil moisture was maintained by the weed barrier fabric and thus evapo-transpiration was reduced (Hild and Morgan 1993). Weingand et al.'s (2004) results would suggest seed production may have been enhanced by winterfat plant "memory" of previous climatic conditions.

Failure of irrigation to increase seed production may be due, in part, to a confounding effect of excess moisture from 2002 and decreased evapo-transpiration due to the weed barrier fabric. Majerus (2003) reported an irrigation benefit that could be the result of depletion of soil moisture and higher evapo-transpiration rates from an unmulched soil. Schellenberg (2002) noted a marked increase in seed yield for plants grown in weed barrier fabric without irrigation.

Average seed yields for 2003 for sites 1and 2 were 38.9 and 42.2 g m^{-2} respectively or 3.3 to 3.5 fold higher yield than that reported (12.0 g m^{-2}) for the Open Range germplasm release during second year growth (Majerus 2002). In contrast, the 2002 seed yield for DU plants was approximately 25% of the reported Open Range germplasm yield. The 2 year average for site 1 was 2 fold higher in seed yield than that of Open Range. Therefore, the results of this study suggest seed production potential of two-year-old DU plants will be sufficient for competitive commercial seed production. More research on temperature stress and water stress effects may elucidate additional constraints to winterfat seed yield availability.

4.3.2 Climatic Conditions

Precipitation, temperature and potential evaporation were previously summarized in Chapter 3. The 2001 and 2003 growing seasons were warm and dry but the 2002 season was cool and wet.

Soil water content (Figures 4.1 and A3) results confirm that 2002 was a wet year at SPARC. Soil water content did not decline below wilting point at any sampling date. Application of irrigation did not increase water content found at 0 to 15 cm compared to no irrigation.

Soil temperature measured at the base of plants also confirms that 2002 was a

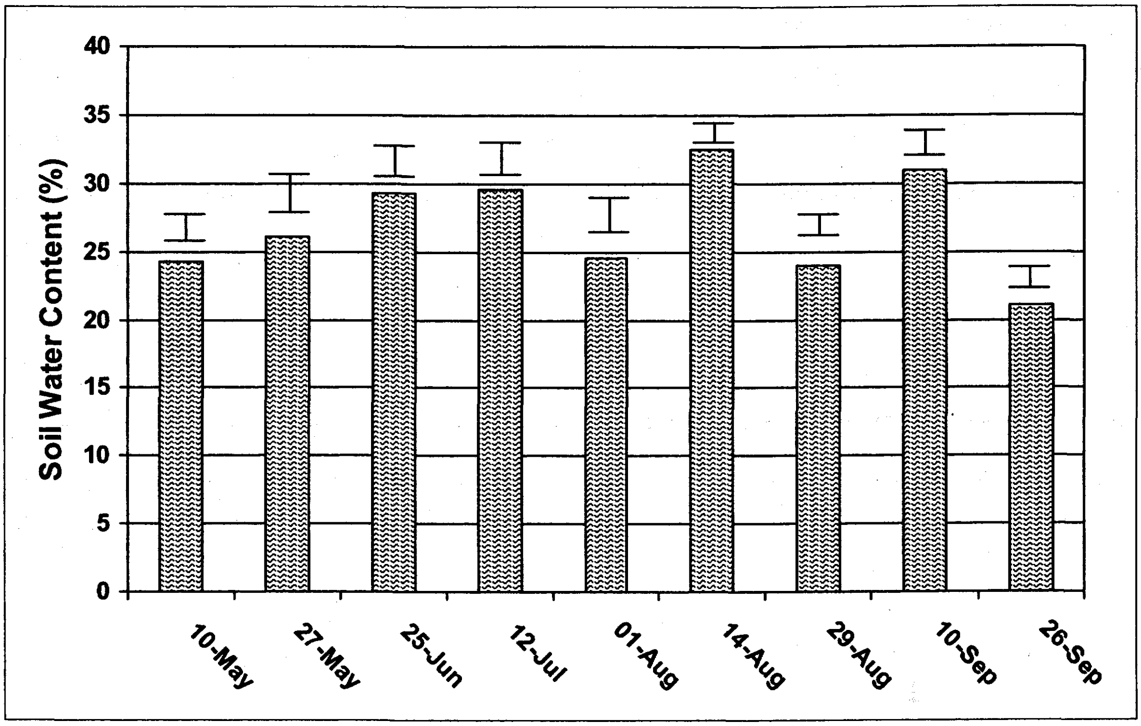

Figure 4.1: Site 1 mean soil moisture readings (0 to 15 cm depth) for the 2002 growing season (10 May, 27 May, 25 June, 12 July, 1 August, 14 August, 29 August, 10 September and 26 September). Soil water content at field capacity is 31.6% and at wilting point 18.7% (Ljundgren, personal communication).

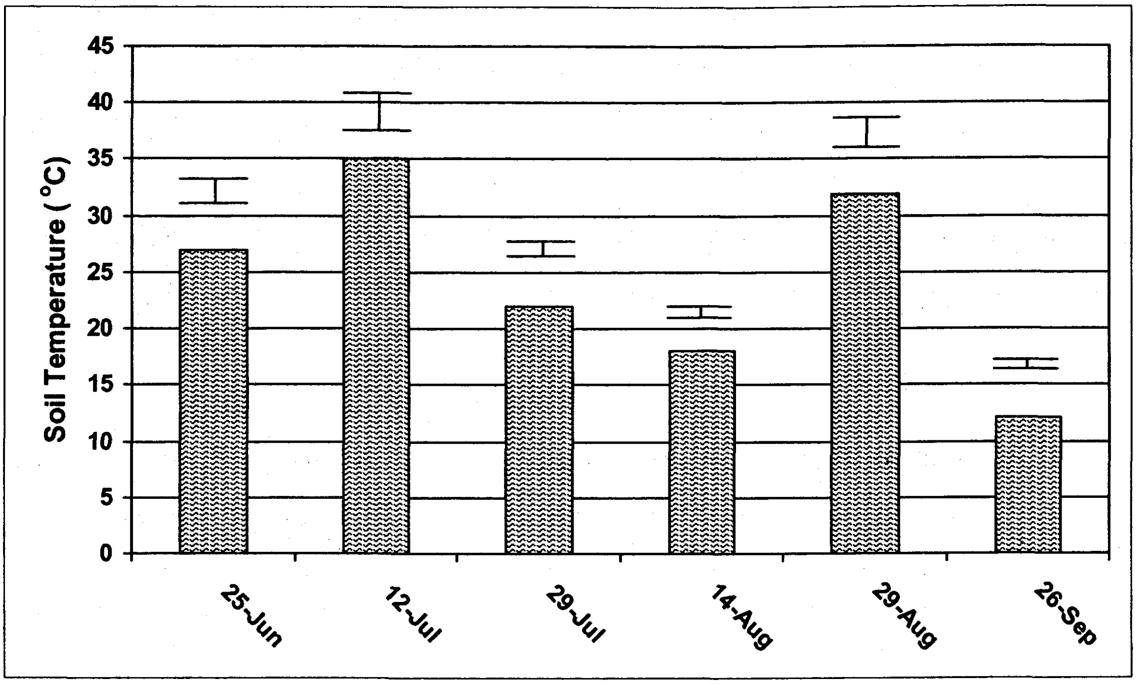

Figure 4.2: Site 1 mean soil Temperatures from base of plants for 2002 growing season (25 June, 12 July, 29 July, 14 August, 29 August, and 26 September). No significant differences were detected for any factors ($P > 0.05$).

cool year (Figure 4.2 and A4). The normally hot month of July, had only a single soil temperature reading within the optimal range (+ 25 °C) reported for New Mexico winterfat seedlings (Schellenberg 2003; Thygerson et al. 2002). Cool temperatures may also explain the failure of the New Mexico winterfat plants to advance beyond the vegetative growth stage during 2002 (Larcher 1995). The soil temperatures were sufficient for phenological development of the Ducks Unlimited ecovar™ plants.

Irrigation treatment did not increase soil moisture in 2003 except on the date immediately following an irrigation treatment. The mean soil moistures were as follows: 19 June 16.3% (SE = 0.4), 17 July 14.0 % (SE = 0.7), 14 August 17.5% (SE = 0.5) and 8 October 19.2% (SE = 0.6). The level of moisture was higher than one would expect for bare soil with the drought conditions encountered. As Hild and Morgan (1993) noted, evaporation from the soil surface decreased when it was covered with material that creates a non-living mulch barrier. On 14 August soil water differed ($P < 0.05$, SE = 0.2) as the August irrigation soil water was 21.2%, no irrigation was 17.8% and October irrigation was 13.6%. Soil water differences were not evident at the June nor the August 2003 sampling dates from the October 2002 application.

Soil temperatures were measured on three dates in 2003 at site 1 for the second year of seed harvest. No differences ($P > 0.05$) in soil temperatures were detected among treatments. The mean soil temperatures were: 30.2°C (SE = 2.1) on 19 June, 36.7°C (SE = 1.7) on 17 July, and 29.9 °C (SE = 3.0) on 14 August .

Soil water concentrations for site 2 (Table 4.4) were significantly greater ($P < 0.05$) for plots with New Mexico plants compared to DU plants. This was likely the result of less soil water depletion by fewer and smaller NM plants. Any irrigation effect from fall of 2002 was not evident in June or July. When sampled six to seven days after irrigation (14 August and 14 October), the recently irrigated treatments had more ($P < 0.05$) soil water. On 8 October no difference ($P > 0.05$) in soil water was detected. As discussed for site 1, soil water concentration was likely higher than would occur in rangeland sites due to the weed barrier fabric .

Plant temperatures at the base of the plants at site 2 (Table 4.5) were lower ($P <$

Table 4.4: Mean soil water (%) for site 2, first year of harvest in 2003. Interactions and fertilizer not significant (P > 0.05) and therefore are not shown. Main Plot (irrigation) and subplot factors (seed source) provided.

Factor	June 19	July 17	Aug 14	Oct 8	Oct 14
Seed Source					
New Mexico	23.1 a	20.1 a	21.2 a	18.5 a	20.7 a
Ducks Unlimited	15.2 b	13.9 b	17.4 b	15.1 b	18.3 b
SE	1.5	1.5	1.8	1.2	2.0
Irrigation					
August	19.2	17.8	24.3 a	15.9	15.9 b
October	19.2	16.9	17.3 b	16.7	26.9 a
None	19.0	16.3	16.2 b	17.8	15.7 b
SE	1.9	1.9	2.3	1.4	2.4

a - b Numbers followed by a different letter for a factor within a column are significantly different (P < 0.05) as determined by the Tukey's test.

Table 4.5: Plant basal temperature means (°C) for first year of harvest in 2003. Interactions and fertilizer not significant ($P > 0.05$) therefore not shown. Main Plot (irrigation) and subplot factor (seed source) provided.

Factor	June 19	July 17	Aug 14
Seed Source			
New Mexico	37.8 a	42.5 a	29.1 a
Ducks Unlimited	32.5 b	37.2 b	26.7 b
SE	1.2	1.2	0.8
Irrigation			
August	34.9	39.3	26.9 b
October	34.9	40.0	29.1 a
None	35.6	40.3	27.8 ab
SE	1.5	1.5	1.0

a - b Numbers followed by a different letter for a factor in a column are significantly different ($P < 0.05$) as determined by the Tukey's test.

0.05) for Ducks Unlimited plants. This was due to either increased shading by the upper canopy or higher transpirational cooling of plant tissue. The much smaller New Mexico plants had less upper canopy to provide shading to lower temperature. The difference ranged from 3 to 5 °C. The basal temperature was determined on the day following irrigation and the August irrigation basal temperature was lower ($P < 0.05$) than the October irrigation treatment with no irrigation plots being intermediate ($P > 0.05$). The basal temperature for the August irrigation treatment was 4 °C cooler than the air temperature.

4.4 Conclusions

New Mexico plants failed to progress to a phenological stage of mature seed production. Ducks Unlimited plants did progress to mature seed production which exceeded yield levels reported from Montana, USA. Seed production for DU plants did not respond to irrigation or fertilization amendments as applied in these experiments. To ensure low-cost, reliable winterfat seed production these agronomic details need to be refined to dampen the observed year-to-year variation in seed production. Once refined, the potential to produce agronomically acceptable yields appears very promising.

Ducks Unlimited plants demonstrated a superior persistence while NM plants did not. There appears to be genetic potential within the DU ecovar for further improvement of persistence in winterfat breeding material.

CHAPTER 5

NUTRITIONAL QUALITY DIFFERENCES WITHIN PLANTS FROM DU AND NM SEED SOURCES

5.1 Introduction

The semi-shrub winterfat, *Krascheninnikovia lanata* (Pursh) A.D.J. Meeuse & Smit, is known for its high nutritive value as a winter forage (Sampson 1924; Smoliak and Bezeau 1967; Abouguendia 1998).Winterfat is a shrub found from Mexico (Springfield 1974) to Canada (Great Plains Flora Association 1986) as far north as Sheep Mountain in the Yukon (Hoefs et al. 1975), but not Alaska (Vetter 2000).

Within the distribution range winterfat is known to have developed ecotypes due to soil type (Workman and West 1969; Goodman 1973), and salinity (Clark and West 1971). Ecotypic differences have been reported for productivity for fruit, seed characteristics, above-ground productivity and degree of tolerance of soil pH (Stevens et al. 1977). Stebbins (1950) defined ecotypes as a distinct genotypic response of many widespread species to a particular habitat. Ecotypic variation is not necessarily morphological in nature. Epstein (1972) indicated there are numerous examples of varietal differences and unexploited potential for ecotypic differences in mineral uptake. He suggested that nutritional ecotypes likely occur and thus associated ecotypic variation in nutritional value. Variation in nutritional value due to mineral uptake has not been previously reported for winterfat.

Differences occur within functional groups (grasses, forbs and shrubs) as well as within species for mineral uptake, carbohydrate composition, lipid and protein concentration (Jones and Wilson 1987). These nutritional components also change as the plant matures (Cook 1972, Kilcher 1981, Jones and Wilson 1987). This relationship between phenological stage and nutritive value is also true of winterfat (Smoliak and

Bezeau 1967). The main benefit of winterfat is its retention of crude protein (CP) concentration at maturity. For example, Smoliak and Bezeau (1967) reported 121 g CP kg^{-1} DM at phenological maturity (ie. seed set), which is a characteristic exhibited by many browse species (Cook 1972, Jones and Wilson 1987). Similar CP concentrations have been reported for winterfat by Crampton and Harris (1969), Ensminger et al. (1990), and NRC (1982) without reference to stage of maturity. Crude protein values reported by Sowell et al. (1985) and Smoliak and Bezeau (1967) suggest a 50 g CP kg^{-1} DM difference between Wyoming and Alberta plant types which is an indication of potential ecotypic differentiation based on nutritive characteristics. Abouguendia (1998) indicated that nutritive values differed among 16 sites in Saskatchewan from which winterfat had been harvested. These reported differences may reflect differences in climatic and edaphic charateristics but may also suggest possible ecotypic variation in nutritive value of winterfat.

Epstein (1972) stated that rates of absorption and translocation of specific nutritional and mineral elements may differ among genotypes within a species. Variation in mineral accumulation can have major impact on nutritive value. For example, some species accumulate selenium to levels that are toxic to livestock. The literature pertaining to mineral concentrations of winterfat is limited to single sites and/or single genotypes (Hamilton and Gilbert 1972, Romney et al. 1980, Wallace and Romney 1972). Potential toxic accumulation of Mo by winterfat occurred on a mine tailings site in Wyoming (Stark and Redente 1990a). However, mine tailings represent a highly disturbed site and Mo accumulation may have been amplified compared to an undistubed native range soil. There is limited mineral concentration information about winterfat and for browse species (Springer et al. 2002) and for native plants in general (Epstein 1972).

Ganskopp and Bohnert (2003) noted there were significant mineral to mineral interactions within grasses and this likely occurs for winterfat as well. Many minerals also exhibited interactions within the animal when digested (Minson 1990). Mineral digestion or availability is dependant on the form in which they occur (Minson 1982), but this topic was beyond the scope of this project.

Winterfat seed can be harvested from wild plants throughout its range with appropriate permission and this is the main source of seed, with New Mexico seed being the most readily available (Wind River Seeds, personal communication). In the United States, through USDA-NRCS, there are three germplasms or seed sources currently available: Hatch from Los Lunas Plant Materials Centre, New Mexico; Northern cold desert germplasm released by Aberdeen Plant Materials Centre and Idaho Agricultural Experiment Station; and Open range germplasm released by Bridger, Montana Plant Materials Center (Ogle et al. 2003). At the time of initiation of this project only Hatch was available.

In co-operation with the Semiarid Prairie Agricultural Research Centre (SPARC)- AAFC, Ducks Unlimited Canada (DU) have developed an ecovar™ or ecological variety of Saskatchewan source winterfat for western Canada. The ecological variety was intended to have a greater genetic diversity than a cultivar. The winterfat ecovar was made up of seed collected from 16 sites in southern Saskatchewan. The resulting plants were grown in a field plot nursery at SPARC. The seed harvested from the SPARC nursery was then bulked and released for seed increase as the winterfat ecovar™ . There was no selection imposed for agronomic characteristics such as seed production, grazing tolerance, or nutritional qualities.

This chapter presents results of nutritional and mineral comparisons of winterfat plants grown from seed originating from the southern (New Mexico, NM) and northern (Saskatchewan, DU) portions of its distribution range. The results are used to evaluate the possibility of ecotypic differentiation within winterfat based on nutritional value.

5.2 Materials and Methods

Random sub-samples of plant material for analyses were obtained from the experiments described in Chapter 3. As plant mineral content of plants will vary depending on the site (Epstein 1972, Norton 1982, Wilson 1982, Spears 1994), plants were grown at a common site and not collected from sites where the seed originated, allowing comparison of plants to be unaffected by edaphic soil mineral concentrations.

5.2.1 Experiment 1

The first three-factor factorial design experiment (Figure A1), with four replicates, was established in spring of 2001 and had plots of 10 transplanted plants (NM or DU) each spaced 0.5 m apart in the row placed in weed barrier fabric (Weed Barrier Landscape Fabric supplied by the Professional Gardener, Calgary). The rows were separated by 1m of fabric covered soil. The factors were: 1) seed source: New Mexico (NM; seed supplied by Wind River Seeds, Wyoming) or Saskatchewan (DU; Ducks Unlimited Canada ecovar™); 2) clipping dates (end of each month): six dates, June to November in 2002, and five dates, June to October, in 2003; and 3) two rates of fertilizer: zero or100 kg N ha^{-1} with 50 kg ha^{-1} phosphorous (P) as P_2O_5. Fertilizer rates for N and P were within the range recommended for cultivated Saskatchewan forage crops (Murrell 1992). Soil available N and P were determined by automated hydrazine reduction extraction and automated acid molybdate/ascorbic acid extraction (Winkleman 1998) of soil samples prior to addition of fertilizer in late June.

Plants were clipped to 50% of height and the harvested material was referred to as harvested production. The harvested production was ground and then was randomly subsampled to provide material for chemical analyses. Clipping commenced the year after establishment, the second year of growth, in 2002. Plant samples were again collected in 2003 for three year old plants.

5.2.2 Experiment 2

Approximately 500 m north of experiment 1, the second experiment was established in spring of 2002 with the same layout. Plants were clipped to 50% of height and the harvested material was referred to as harvested production. The harvested production was ground and then was randomly subsampled to provide material for chemical analyses. Plant samples were collected from 2 plants per plot in fall of 2002 for one year old plants at experiment 2. Plant samples were again collected in 2003 for two year old plants.

5.2.3 Ducks Unlimited Winterfat Leaves and Stems

In 2003, leaf and stem tissues were obtained separately from 15 cm lengths of shoot with a complete growing point for both experiments.

5.2.4 Sample Preparation and Chemical Analyses

Samples were dried at 60° C in forced-air ovens to a constant weight. Dry samples were ground in a Wiley mill to pass through a 1-mm screen, labelled and placed in glass jars. Analyses performed were: ether extract (AOAC 1984); in vitro organic matter digestibility (OMD) and organic matter (OM) (Tilley and Terry (1963) as modified by Troelsen and Hanel (1966)); acid detergent fibre (ADF) and neutral detergent fibre (NDF) (Goering and Van Soest 1970); and nitrogen concentration (AOAC 1984) which were converted to crude protein by multiplying by 6.25. Plant samples underwent a Kjeldahl digest (AOAC 1984) for total N, total P and total K. Total Kjeldahl N and total P were determined using a Technicon Autoanalyzer II® system utilizing Setpoint standard nutrients #37049 (Certified Laboratory Setpoint Standard, Analytical Products Group, Inc. 2730 Washington Boulevard, Belpre, Ohio, 45714) every 40 samples to maintain accuracy (Varley 1966). K and Na were analyzed using flame atomic absorption spectroscopy (Kalra 1998); calcium (Ca) concentration was determined after nitric-perchloric acid digestion (Kalra 1998); magnesium (Mg), iron (Fe), zinc (Zn), manganese (Mn), sulphur (S), cadmium (Cd), and copper (Cu) concentrations were determined following digestion with $HClO_4/HNO_3$. Cd, Cu, and Co concentrations were determined using graphite furnace atomic absorption spectroscopy. Sulphur, Ca, Mg, Fe, Zn, Mn, and Se were determined using inductively coupled argon plasma spectroscopy (atomic emission spectroscopy) (Kalra 1998). Selenium (Se) concentrations were determined with atomic flame absorption spectroscopy after samples were digested with $HClO_4/HNO_3/HCl$ digest (Kalra 1998). Molybdenum (Mo) and boron (B) concentrations were determined with graphite furnace atomic absorption spectrophotometry after samples had undergone a $HClO_4/HNO_3/HCl/H_2SO_4$ digestion (Kalra 1998).

Molybdenum was included in mineral analyses due to winterfat being suggested as an accumulator in the literature (Stark and Redente 1990a). Cadmium was included in the mineral analysis due to noted above national average amounts present in the soil at the experimental sites (Dr. Selles, personal communication).

Boron and molybdenum analyses were run for the DU plant samples only due to insufficient sample remaining from the New Mexico plants after other chemical analyses had been completed.

Analytical instrumentation, lamp, wavelength settings, flame/ plasma gas, gas flow rate, optic/detector chamber conditions, standards range, lower detection limits, standard recalibration frequency, National Institute of Standards and Technology reference material, and Analytical Products Group setpoint standard are noted in Table A13 for all minerals except P. Molybdenum and B were analysed in duplicate by NorWest Laboratories (Edmonton, AB). The other mineral concentrations were determined by the Analytical Chemistry Group, Semiarid Prairie Agricultural Research Centre (SPARC) - Agriculture and Agri-Food Canada (AAFC).

5.2.5 Statistical analyses

Data were tested for fit to normal distribution using the Shapiro-Wilk test (SAS 1999). All data were statistically analysed for all main factors, two and three way interactions using ANOVA for individual years using Proc GLM (SAS Institute, Inc. 1999). Standard error (SE) was calculated (Steel and Torrie 1980). Simple linear correlations (Gomez and Gomez 1984) were calculated for ADF and NDF with stage of growth and primary and secondary branch diameter with OMD for material collected in 2003. When the factor was significant, at $P < 0.05$, a Tukey's test was calculated for mean separation (Steel and Torrie 1980). Only significant interactions are discussed.

5.3 Results and Discussion

Results of Shapiro-Wilk test indicated the data, except the leaf/stem data, were normally distributed. Leaf/stem data were transformed using the square root transform (Steel and Torrie 1980). Variance decreased but no improvement for F-test probabilities was observed. Therefore original data scale results are reported for simplicity.

5.3.1 Minerals

5.3.1.1 Seed Source

5.3.1.1.1 Year 2002

In fall 2002, after one year of growth (experiment 2), Mg, Cu, and Se were not different ($P > 0.05$) between winterfat seed sources, however there were significant differences ($P < 0.05$) for all other minerals studied (Table 5.1). This result suggests that these two seed sources exhibit different capacities to absorb and concentrate minerals. Zinc, Cu, Co, and Se concentrations were deficient in DU plants while Cu and Co were deficient in New Mexico plants compared to the mineral requirements of a medium-framed British breed replacement heifer in the first trimester (NRC 2000, Table A5). Sulfur and Mg for both seed sources, and Fe concentration for DU plants, were at or over the maximum tolerance for the age and type of animal.

For 2002 plants with two years of growth (experiment 1), mean Co and Na concentration were not different ($P > 0.05$) between seed sources (Table 5.2). Fertilizer application decreased ($P < 0.05$) the amount of Ca but did not affect ($P > 0.05$) the concentration of any other minerals. Cobalt and Fe concentration peaked on the July sampling date, while Na concentration increased until the September sampling date . A medium-framed British breed replacement heifer in the first trimester would have inadequate Se, Cu and Co for fall grazing. Ca, Na, and Fe concentrations in October and November would be adequate. Cadmium levels are below the toxic concentration (NRC 2000, Table A5) limit for DU plants but are at the maximum level for the New Mexico seed source. Boron and molybdenum concentrations were below toxic levels (data not shown). Boron concentrations, for 2002, were below measurable amounts (< 0.5 mg kg^{-1} DM). Molybdenum concentration was below measurable amounts (< 0.5 mg kg^{-1} DM) for all samples analyzed during 2002 and 2003.

Winterfat crude protein, K, S and Mn concentrations were adequate for fall grazing by a medium-framed British breed replacement heifer in the first trimester. New Mexico plants were significantly higher ($P < 0.05$) than DU plants for all mineral concentrations except Mn and S (Table 5.3). DU plants had higher ($P < 0.05$)

Table 5.1: Crude protein and mineral content of plants after one growing season sampled in fall 2002 (experiment 2). Fertilizer was not included due to no statistical difference ($P > 0.05$).

Mineral	DU Plants	New Mexico Plants	SE
	------------------g kg^{-1} DM	----------------	
Crude Protein	141.3	186.7*	7.8
Ca	21.2*	18.1	0.8
P	2.5	3.4*	0.2
K	17.0	19.0*	0.8
Mg	9.7	9.2	0.4
Na	0.08*	0.07	0.004
S	4.1*	3.8	0.2
	----------------mg kg^{-1} DM	---------------	
Mn	108.1*	96.7	5.2
Zn	26.3	40.2*	3.3
Cu	0.98	0.68	0.7
Fe	1141.9*	721.5	157.3
Co	0.033*	0.016	0.008
Se	0.038	0.041	0.009
Mo	na	na	
Cd	0.037	0.053*	0.005
B	na	na	

* - Significantly different between seed sources ($P < 0.05$).
na - not available

Table 5.2: Mineral (Ca, Cu, Co, Fe, Na, Se, Cd) content of winterfat plants in their second year of growth harvested during 2002 (experiment 1) in which no significant (P > 0.05) interactions occurred.

	Minerals						
	Ca	Cu	Co	Fe	Na	Se	Cd
Factors	**g kg^{-1} DM**	------------------	------------------	**mg kg^{-1} DM**	------------------	------------------	------------------
Seed							
DU	13.0 a	0.40 b	0.023	868.6 a	48.8	0.087 a	0.028 b
New Mexico	11.0 b	0.53 a	0.013	626.3 b	50.3	0.055 b	0.050 a
SE	0.6	0.04	0.009	157.8	5.1	0.012	0.007
Clipping Date							
June	12.0	0.50	0.011 b	631.7 b	42.8 b	0.081	0.032
July	12.4	0.48	0.055 a	1338.0 a	40.0 b	0.069	0.041
August	12.3	0.45	0.020 b	868.1 ab	39.2 b	0.073	0.034
September	12.4	0.44	0.004 b	448.7 b	64.0 a	0.065	0.040
October	12.5	0.46	0.013 b	555.9 b	49.6 ab	0.083	0.051
November	11.2	0.48	0.006 b	640.1 b	61.7 a	0.055	0.035
SE	1.0	0.06	0.016	276.2	8.9	0.021	0.012
Fertilizer							
Fertilized	11.6 b	0.46	0.019	778.1	50.9	0.065	0.039
Non-Fertilized	12.6 a	0.47	0.017	716.9	48.2	0.077	0.039
SE	0.6	0.04	0.009	157.8	5.1	0.012	0.007

a - b Factor means within the column followed by a different letter are significantly different (P < 0.05) as determined by the Tukey's test.

Table 5.3: Crude protein and mineral (K,P,Mg,S,Mn,Zn) content of winterfat plants in their second year of growth harvested during 2002 (experiment 1) in which the Seed x Date interaction and seed type (DU, and NM) were significant (P < 0.05).

	Crude Protein		K		P		Mg		S		Mn		Zn	
Factor	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM
Units	g kg^{-1} DM										mg kg^{-1} DM			
Seed Source	126 b	139 a	16.7 b	20.2 a	1.8 b	2.1 a	6.8 a	5.1 b	2.6	2.6	100.0 a	90.9 b	19.3 b	24.4 a
SE	1.4		0.3		0.1		0.9		0.1		2.0		0.4	
Clip Date														
June	168 a	160 ab	24.4 a	24.7 a	2.6 a	2.2 ab	5.9 bcd	4.8 d	3.3 a	2.8 abc	70.6 c	89.0 bc	20.0 abcd	26.1 ab
July	138 bc	137 bc	17.0 cd	19.2 c	2.2 ab	2.0 b	6.7 bc	4.8 d	2.4 bcd	2.1 cd	123.5 a	96.5 abc	23.6 abc	25.9 ab
Aug.	128 c	131 c	17.8 cd	20.1 bc	1.9 b	1.9 b	6.7 bc	5.1 d	2.8 abc	2.3 bcd	97.3 abc	93.1 abc	20.4 abcd	20.3 abcd
Sept.	127 c	144 bc	16.9 cd	21.1 abc	1.8 bc	2.3 ab	8.3 a	5.3 cd	3.0 ab	3.0 ab	97.7 abc	94.1 abc	19.0 bcd	23.0 abcd
Oct.	99 d	128 c	13.7 de	18.9 c	1.3 cd	1.9 b	7.1 ab	5.5 cd	2.5 abcd	2.9 ab	108.0 ab	82.8 bc	16.7 bcd	24.4 ab
Nov	95 d	134 c	10.6 e	17.2 cd	1.2 d	2.1 ab	6.1 bcd	5.1 d	1.9 d	2.4 bcd	104.4 ab	89.2 bc	16.0 d	26.5 a
SE	5.0		1.2		0.7		1.3		0.6		26.0		0.6	

a - d Means followed by a different letter within the two columns for clip date and within the row for seed source under a mineral are significantly different (P < 0.05).

concentration of Mn. Sulphur did not differ between the two seed sources ($P > 0.05$). New Mexico plants had adequate concentrations of Zn and P but the DU plants were deficient. The higher ($P < 0.05$) concentrations of CP, Zn and P in NM plants were probably due to the failure of the plants to mature. Mineral and CP concentrations decrease as plants mature, although mineral concentrations in shrubs decrease at a slower rate than that of many grasses or forbs (Cook 1972). Manganese exhibited the opposite trend for DU plants, indicating accumulation as the growing season progressed but New Mexico plants did not mature and therefore final Mn concentration uptake may have been affected.

New Mexico plants accumulated more Cd, Zn, K and P while DU plants accumulated more Ca, Cu, Mn, Fe, and Co in the first year of growth (experiment 2) (Table 5.1). For the second year of growth (experiment 1) (Tables 5.2 and 5.3), DU plants accumulated more Se whereas New Mexico plants accumulated more Cu, Cd and S. The other minerals remained similar to the site 2 one year old plant concentrations. Crude protein in New Mexico plants was higher ($P < 0.05$) than DU in both age groups for 2002.

5.3.1.1.2 Year 2003

As in 2002, mineral concentrations for 2003 showed that the two seed sources accumulated most minerals differently (Table 5.4). Most trends for 2003 were similar to 2002 with the following exceptions: 1) Na concentration was higher ($P < 0.05$) for NM plants than DU plants in the second year of growth (experiment 2) and there was no difference ($P > 0.05$) due to seed source for three year old plants (experiment 1), 2) S concentration was not different ($P > 0.05$) due to seed source for both two (experiment 2) and three year old (experiment 1) plants, and 3) Cu concentrations differed ($P < 0.05$) between seed sources. Most mineral concentrations were lower in 2003 compared to 2002 with the exception of B, Mn, Co and Se. Cobalt and selenium doubled in concentration in 2003 compared to 2002 but remained well below the maximum tolerable. Magnesium concentration was twice the maximum tolerable as in 2002. The decrease in forage mineral concentrations may be due to year-to-year variation of soil mineral concentrations which can be affected by changing pH, soil organic content, mineralization and

Table 5.4: Crude protein and mineral concentration of plants by seed source for the second (experiment 2) and third (experiment 1) year of growth in 2003.

	Two year old plants			Three year old plants		
Mineral	DU	NM	SE	DU	NM	SE
	------ **g kg $^{-1}$ DM** ------					
Crude protein	132 b	164 a	5.4	110 b	142 a	7.1
Ca	15.9 a	15.0 b	0.5	13.3	13.3	0.5
P	2.0 b	2.1 a	0.1	1.5 b	1.8 a	0.1
K	16.5 b	17.7 a	0.7	15.8 b	19.3 a	1
Mg	8.3 a	7.6 b	0.3	7.1	6.5	0.4
Na	0.06 b	0.13 a	0.02	0.07	0.07	0.01
S	2.9	2.8	0.1	2.6	2.8	0.1
	------ **mg kg $^{-1}$ DM** ------					
Mn	116.3 a	106.4 b	5.8	121.8 a	93.3 b	5.4
Zn	21.3 b	35.8 a	2.5	18.5 b	22.7 a	1
Cu	0.43 b	0.61 a	0.04	0.45 b	0.56 a	0.02
Fe	934 a	555 b	123	843 a	480 b	65
Co	0.078 b	0.099 a	0.01	0.068 a	0.051 b	0.005
Se	0.066	0.056	0.006	0.11	0.1	0.011
Cd	0.030 b	0.047 a	0.003	0.026 b	0.039 a	0.004
B	na ^{z}	na	na	28.8	na ^{y}	1.3
Mo	na	na	na	<0.5	na	na

a - b In the row means each age of plant followed by different letters are significantly different ($P < 0.05$) as determined by the Tukey's test.
^{z} - results not available due to no sample submitted for analyses
^{y} - insufficient sample available for New Mexico plants to be analyzed

soil moisture content (Tisdale and Nelson 1975). The decrease may have also been due to dilution by increased biomass production. Cobalt and Mn had similar concentrations for both 2 (experiment 2) and 3 (experiment 1) year old plants.

5.3.1.2 Clipping Date

Some minerals did not have a significant ($P > 0.05$) seed source x date of clipping interaction for 2002 (Table 5.2) and 2003 (Table 5.6) nor did they differ between the 2nd (Table 5.5, experiment 2) and 3rd year of growth (Table 5.6, experiment 1). In 2002, Fe and Na did not have a significant ($P > 0.05$) seed source x date of clipping interaction but did in 2003 (Table 5.8). In 2003 (Table 5.5), Mn did not have a significant ($P > 0.05$) seed source x clipping date interaction for the 2 year old plants (experiment 2). Calcium, Mn, and Cd concentration increased as the growing season progressed in 2003 and Se peaked ($P < 0.05$) at the August sampling date (Table 5.5). Copper and Co concentrations were similar over the clipping dates for the 2 year old plants. Similar trends for three year old plants (experiment 1) and two year old plants (Experiment 2) were noted for Ca and Cu (Table 5.6). Selenium concentration remained unchanged during the growing season for three year old plants (experiment 1) (Table 5.6), while Se concentration increased over the clipping dates for two year old plants (experiment 2) (Table 5.5). Cobalt for both years (2002 and 2003) and both two (experiment 2) and three (experiment 1) year old plants exhibited a decreased concentration during flowering and seed production with a rebound once the reproductive cycle was complete, possibly because there was Co translocation to seed from leaf and stem tissues.

The seed source x date of clipping interaction was significant ($P < 0.05$) for two year old plants (Table 5.7, experiment 2) and for three year old plants (Table 5.8, experiment 1) for crude protein, P, K, Mg, Na, S, Zn and Fe concentrations. For the two year old DU plants (Table 5.3, experiment 1) in 2002, Zn concentration declined ($P < 0.05$) while that of NM plants remained constant. In 2003, the two year old plants for both DU and NM decreased (Table 5.7, experiment 2) in Zn concentration, as observed for grasses and legumes (Minson 1990, MacPherson 2000). The DU three year old plants (Table 5.8, experiment 1) had the same trend but NM plants started

Table 5.5: Effect of clipping date on mineral (Ca, Cu, Co, Se, Mn, Cd) concentration of winterfat plants in their second year of growth (experiment 2) harvested during 2003. No significant (P > 0.05) interactions or fertilizer effect occurred.

	Minerals					
Factors	Ca	Cu	Co	Se	Mn	Cd
	g kg^{-1} DM	---------- **mg kg^{-1} DM** ----------				
Clipping Date						
June	13.1 c	0.45	0.074	0.035 c	68.7 c	0.024 b
July	14.9 bc	0.46	0.106	0.056 c	87.7 c	0.033 ab
August	16.4 ab	0.51	0.087	0.095 a	121.4 b	0.033 ab
September	15.3 abc	0.49	0.074	0.065 b	123.6 ab	0.040 a
October	17.1 a	0.55	0.085	0.062 bc	138.7 a	0.044 a
SE	0.9	0.08	0.02	0.011	9.6	0.006

a - c Within the column means followed by a different letter are significantly different (P< 0.05) as determined by the Tukey's test.

Table 5.6: Effect of clipping date or fertilizer on mineral (Ca, Cu, Co, Se, B, Cd) concentration of DU winterfat plants in their third year of growth (experiment 1) harvested during 2003. No significant (P > 0.05) interactions occurred.

	Minerals					
Factors	Ca	Cu	Co	Se	B*	Cd
	g kg^{-1} DM	---------- **mg kg^{-1} DM** ----------				
Clipping Date						
June	13.4 ab	0.53	0.068 ab	0.11	----	0.026
July	13.2 ab	0.47	0.057 b	0.12	----	0.036
August	12.4 b	0.49	0.053 b	0.12	30.6 a	0.034
September	13.6 ab	0.51	0.054 b	0.09	24.9 b	0.028
October	14.3 a	0.52	0.079 a	0.09	31.0 a	0.033
SE	0.8	0.04	0.009	0.02	1.6	0.005
Fertilizer						
Fertilized	13.3	0.45 b	0.069 a	0.11	26.9 b	0.026 b
Non-fertilized	13.3	0.57 a	0.051 b	0.11	30.8 a	0.039 a
SE	0.5	0.02	0.005	0.01	0.9	0.003

a - b Within the column means followed by a different letter are significantly different (P < 0.05) as determined by the Tukey's test.
* - Due to lack of NM plant sample only DU plants analyzed.

Table 5.7: Effect of clipping date on crude protein (CP) and mineral (P, K, Mg, Na, S, Zn, Fe) concentration of DU and NM winterfat plants in their second year of growth (experiment 2) during 2003. Significant (P < 0.05) Seed Source x Clipping Date interaction occurred but no significant (P > 0.05) fertilizer effect.

	CP		**P**		**K**		**Mg**		**Na**		**S**		**Zn**		**Fe**	
Seed	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM
Units	---------- g kg $^{-1}$ DM ----------												---------- mg kg $^{-1}$ DM ----------			
Clip Date																
June	186 a	-----	3.3 ab	------	24.3 a	------	5.3 b	------	0.03 c	------	2.5 bcd	-----	25.9 ab	------	670 b	------
July	140 ab	200 a	2.3 b	2.8 b	20.0 ab	23.6 a	6.2 ab	7.1 ab	0.03 c	0.07 c	3.4 a	3.3 ab	25.4 ab	38.2 a	1072 ab	458 c
Aug	135 bc	124 bc	2.0 cd	1.4 cd	13.8 bc	13.2 bc	9.3 ab	5.8 b	0.03 c	0.05 c	2.8 abcd	2.3 d	20.1 b	28.4 ab	885 b	949 b
Sept	117 bc	162 ab	1.6 c	1.9 c	12.5 c	17.0 abc	10.3 a	8.1 ab	0.04 c	0.03 c	2.4 cd	2.8 abcd	17.4 c	27.7 ab	674 b	528 c
Oct	82 c	168 ab	1.0 d	2.3 b	12.0 c	18.3 abc	10.6 a	8.4 ab	0.14 b	0.34 a	2.0 d	2.2 d	17.8 c	47.5 a	1368 a	428 c
SE	9.9		0.1		1.4		0.6		0. 01		0.2		1.4		94.3	

a - d Within the two columns of a mineral, means followed by a different letter are significantly different (P < 0.05) as determined by the Tukey's test.

Table 5.8: Effect of clipping date on crude protein (CP) and mineral (P, K, Mg, Na, S, Mn, Zn, Fe) concentration of DU and NM winterfat plants in their third year of growth (experiment 1) during 2003. Significant (P < 0.05) Seed Source x Clipping Date interaction occurred.

	CP		P		K		Mg		Na		S		Mn		Zn		Fe	
Seed	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM
Unit	g kg $^{-1}$ DM												mg kg $^{-1}$ DM					
Clip Date																		
June	151 b	201 a	2.2 ab	2.6 a	22.0 ab	25.3 a	5.5 ab	6.8 ab	0.03c	0.04c	2.5 bc	3.1 ab	102.0 bcd	112.7 bcd	23.1ab	27.5 a	767 b	693 bc
July	112 bc	140 bc	1.7 c	1.6 c	16.9 bcd	19.8 abc	6.7 ab	6.2 ab	0.03c	0.04c	3.4 a	2.7 abc	104.3 bcd	72.1 d	19.3 bc	24.6 ab	460 bc	243 c
Aug.	102 bc	117 bc	1.3 cd	1.3 cd	13.3 d	15.9 cd	7.3 ab	6.3 ab	0.03c	0.05c	2.8 ab	2.2 bc	112.1 bc	97.2 cd	17.0 c	17.0 c	523 bc	424 bc
Sept	115 ab	128 bc	1.4 c	1.6 bc	14.8 cd	17.0 bcd	7.9 a	7.5 ab	0.03c	0.03c	2.4 bc	2.7 abc	131.0 ab	129.6 abc	16.3 c	22.8 abc	819 b	747 bc
Oct.	70 c	106 bcd	0.9 d	1.3 cd	11.4 d	18.3 abcd	8.3 a	5.3 b	0.21b	0.35a	2.1c	2.2 bc	160.3 a	82.5 cd	16.8 c	18.3 bc	1627 a	370 bc
SE	9.0		0.1		1.4		0.6		0.01		0.2		8.7		1.4		110	

a - d Within the two columns of a mineral, means followed by a different letter are significantly different (P < 0.05) as determined by the Tukey's test.

higher in Zn concentration than DU plants while the latter were lower in fall. For P, K, Zn and S there was a noted decline in concentration as the season progressed for both plant types, although NM plants declined at a slower rate likely due to delayed or slower phenological development. Plants from the DU seed source decreased in CP and K ($P < 0.05$). Sodium concentration increased over the season for both plant types and experiments but the largest increase in Na concentration occurred in the fall, NM plants had a higher concentration in fall ($P < 0.05$). Na is absorbed passivley in transpirational water flow from soil, through roots, xylem and leaves. This large increase in Na concentration in October suggests that transpirational water loss is very high during this period. Iron concentration increased ($P < 0.05$) for DU three year old plants (Table 5.8, experiment 1) with DU plants having a higher concentration in fall for both 2 and 3 year old plants ($P < 0.05$). New Mexico plants did not differ ($P > 0.05$) over the season for either age (Table 5.7, experiment 2 ;Table 5.8, experiment 1) but Fe concentration was lower ($P > 0.05$) than DU for both ages. Iron concentration was numerically greater in three year old plants than two year old plants (Table 5.4). For DU plants Mg concentration increased until the final clipping date with the greatest concentration occurring in October for three year old plants (Table 5.8). The Mg concentration of two year old DU plants (Table 5.7) followed a similar pattern. The two year old (Table 5.7) and three year old (Table 5.8) NM plants showed no trend in Mg concentration.

5.3.1.3 Fertilizer

The addition of fertilizer decreased ($P < 0.05$) the concentration of Cu, B, and Cd (Table 5.6) while increasing ($P < 0.05$) Co (Table 5.6) and Na (Table 5.9) for both DU and NM plants. Iron concentration increased ($P < 0.05$) with added fertilizer in DU plants and fertilization also increased ($P < 0.05$) S in NM plants (Table 5.9). The impact of fertilization had an inconsistent effect on mineral content and only for three year old plants (site1), which suggests that there was a delayed response to fertilizer.

5.3.1.4 Combined Factor Discussion

Direct comparison with concentrations noted for winterfat within the literature would fail to take into account site differences but the following trends can be noted.

Table 5.9: Effect of fertilizer on mineral (Fe, Na, S) concentration of winterfat plants in their third year of growth (2nd harvest) harvested during 2003 for seed source (Ducks Unlimited (DU), New Mexico (NM)) in which a significant (P < 0.05) Seed x Clipping Date interaction occurred. No fertilizer effects (P > 0.05) were noted for other minerals.

	Fe		**Na**		**S**	
Seed Source	DU	NM	DU	NM	DU	NM
	----------	----------	---------- mg kg^{-1} DM	----------	----------	----------
Fertilized	957.7 a	524.5	78.2 a	86.3 a	2682.3	3114.3 a
No Fertilizer	739.9 b	434.6	56.1 b	58.2 b	2569.9	2451.7 b
SE	67.5	63.3	6	6.9	107	169.7

a - b Within the column means followed by a different letter are significantly different (P < 0.05) as determined by the Tukey's test.

Overall trends for crude protein, Ca and P were in agreement with Smoliak and Bezeau (1967) and Abouguendia (1998) regardless of environmental conditions encountered in 2002 or 2003 (see chapter 3). Similar trends are noted for grasses and legumes (Cook 1972, Minson 1990). In contrast to the report of Stark and Redente (1990a), Mo did not accumulate but high levels of Fe and Mg were noted. Wallace and Romney (1972) noted that K concentration was greatest during active growth while K declined during 2002 and 2003 in this study. They also noted a decrease in Ca over the season whereas in this study no difference was observed during 2002 and an increase in Ca concentration occurred during 2003. Wallace and Romney (1972) also noted Zn, Cu, Fe, Mn and Al decreased for Nevada winterfat plants. Copper and Zn concentrations are known to decline in grasses and legumes as the growing season progresses (Minson 1990). For this present study, Mn and Mg concentrations peaked at the seed-set growth stage for plants established in 2001(experiment 1), while plants established in 2002 (experiment 2) exhibited a decline in concentration, similar to Nevada results. Zinc peaked at anthesis, then concentrations declined for all plants regardless of year. Fe concentration peaked during seed production in 2002 (a wet year) but had no trend in 2003 (a dry year). Ducks Unlimited plants declined more rapidly in crude protein, K, P, S, Mn and Zn concentration than NM plants. A greater rate of accumulation was noted for Mg, Mn and Fe in DU plants than in NM plants. These trends in accumulation may be attributed to a lack of phenological maturation in NM plants. Delayed phenologically development would result in plants not exhibiting typical changes in mineral concentrations that are typical of maturing plants.

Differences between the literature and the mineral contents of this study for winterfat could reflect the soil concentrations or climatic conditions. For example, high Mo content of tailings or extreme drought conditions found in the Nevada desert produced high Mo concentrations. These environmental differences could contribute to formation of ecotypes (Workman and West 1969;Clark and West 1971 Epstein 1972; Goodman 1973). Minson (1990) and MacPherson (2000) both noted differences between grasses and legumes and species within grasses or legumes. Therefore shrubs may accumulate minerals differently than legumes or grasses.

Tisdale and Nelson (1975) noted the ratio of some minerals such as Fe : Cu can effect uptake. Assuming the ratio in plants somewhat resembled the minerals in the soil there was potential Fe to interfere with Cu uptake. Low soil Cu concentration will result in low plant concentrations (MacPherson 2000). MacPherson (2000) noted that wet climatic conditions will also decrease the concentration of Cu in plant material which have been a factor in 2002 but unlikely in 2003 for this study.

The following minerals were noted as deficient: Zn, Cu, Co, Se and P. The low total P could lead to reduced feed intake, pica, reduced rates of gain, low conception rates, reduced milk production, poor appearance and rickets (Kincaid 1988). The impacts of P deficiency are hard to detect due to non-specificity and are often confounded by concurrent low energy intakes (Cohen 1980). Availability of copper, an essential component of a number of enzymes, is decreased by the presence of S, Mo (NRC 2000) and Fe (MacPherson 2000). Different breeds also require differing amounts of Cu (NRC 2000). Copper deficiency has been known to provide the following signs anemia, reduced growth, loss of pigmentation and changes in growth of hair, cardiac failure, fragile bones, diarrhea and low live weight gain characterized by delayed or depressed estrus (NRC 2000). Insufficient amounts of Co, a component of vitamin B_{12}, can result in decreased intake, failure to grow, and weight loss initially (NRC 2000). If the deficiency is allowed to become severe, unthriftiness, rapid weight loss, fatty degeneration of the liver, and pale skin and mucous membranes can occur as a result of anemia (NRC 2000). Selenium is a component of glutathione peroxidase which prevents oxidative damage to body tissues. In deficient amounts low Se results in white muscle disease (NRC 2000). Zinc is an essential component of a number of important enzymes and Zn deficiency can result in cattle with reduced growth, reduced feed intake, reduced feed efficiency, listlessness, excessive salivation, reduced testicular growth, swollen feet with open scaly lesions, parakerotic lesions and failure of wounds to heal (NRC 2000).

Minerals found in excess of requirements were S, Mg and Fe. Sulfur in excess can interfere with Cu absorption and can also reduce feed intake and retard growth (NRC

2000). Magnesium toxicity is normally not a problem for beef cattle; i.e. cows fed 3.9 g Magnesium kg^{-1} DM showed no adverse effects while young calves fed 13.0 g Magnesium kg^{-1} DM had lower feed intake and weight gain and diarrhea with mucus in the feces (NRC 2000). Magnesium concentrations in this study were intermediate of these reported values. Iron is an essential component of a number of proteins in oxygen transport and utilization, but at toxic levels causes depletion of Cu, diarrhea, metabolic acidosis, hypothermia, and reduced gain and feed intake (NRC 2000).

Low levels of Cu combined with high levels of S and Fe suggests that Cu supplementation may be needed if winterfat is grazed in a pure stand. However most pastures will be mixtures with grasses, forbs and possibly other shrub species which will provide other sources of Cu.

5.3.2 Fat, Fibre and Organic Matter (Proximate Analysis)

5.3.2.1 Year 2002

In 2002 DU plants had greater ($P < 0.05$) lipid concentration with an ether extract value of 19.7 g kg^{-1} DM than NM plants which had 15.7 g kg^{-1} DM (SE = 0.3). These values are considerably lower than the 28 g kg^{-1} DM reported by NRC (1982) and Ensminger et al. (1990), or the 24.8 g kg^{-1} DM reported by Hamilton and Gilbert (1972). Hamilton and Gilbert (1972) noted their estimate was made for plants at flowering. The lower values observed for our material is the average over the growing season but also includes plants at seed maturity. There was no significant difference between dates of clipping ($P = 0.2$) or fertilizer treatments ($P = 0.7$) for ether extract.

In 2002, organic matter concentration increased as the season progressed but organic matter digestibility (OMD) decreased (Table 5.10). The decrease in digestibility can be attributed in part to increased ADF and NDF concentrations. Fibre concentrations increased as the plant developed and elongated. Elongation requires structural carbohydrates such as hemicellulose and lignin for erect growth (Jones and Wilson 1987, Van Soest 1994). Lignocellulose (ADF) represented 65% of the total fibre present in the NDF. The New Mexico plants had greater NDF and organic matter concentrations ($P < 0.05$) than the DU plants. The DU and NM plants (Table 5.11) had similar trends for

OM and OMD with DU plants having lower OM ($P < 0.05$) in July and lower OMD ($P < 0.05$) in November. The OM increased while OMD declined. At the earlier phenological stage, the fibre of NM is less lignified and therefore more digestible. This might suggest the New Mexico plants would be more nutritionally desirable if this occurs annually. Kilcher (1981) noted a 20% decrease in digestibility for alfalfa with onset of seed set. The lack of seed productivity by New Mexico plants would be a drawback as they would not be able to replace themselves from seed.

5.3.2.1 Year 2003

New Mexico plants exhibited less fibre ($P < 0.05$) in 2003 than DU plants (Table 5.12). For the younger DU plants NDF exhibited an increase ($P < 0.05$) from June to July clipping date but NM plants showed no trend for ADF or NDF ($P > 0.05$) (Table 5.13). This occurred because of the failure of NM plants to again complete their reproductive cycle (see chapter 3). The higher concentration for DU plants coincided with flowering. ADF and NDF concentrations were correlated with stage of growth ($P < 0.05$) (Table A7) for both ages of DU plants and three year old NM plants had. Two year old NM plant NDF concentration was correlated ($P < 0.05$) with stage of growth. For the three year old plants only NM plants showed an increase ($P < 0.05$) in ADF. The NDF concentration peaked in August for both plant types, as did ADF concentration. Fertilizer increased ($P < 0.05$) only the level of NDF in DU plants in the plants with a 2nd year of growth.

Organic matter and organic matter digestibility were not different ($P > 0.05$) between seed sources for plants with two years of growth but differed significantly ($P < 0.05$) for plants with three years of growth (Table 5.14). Both DU and NM plants retained good digestibility values for the fall period with the younger plants having greater digestibility (Table 5.15) which was likely due to less accumulated lignins (less old growth) (Kozlowski and Pallardy 1997). DU plants had the lowest OMD in September and October ($P < 0.05$). Declines over the growing season were noted for OM and OMD concentrations for DU plants, and both ages. DU plant primary branch diameter and secondary branch diameter were negatively correlated with OMD ($P <$

Table 5.10: Means of acid detergent fibre (ADF), neutral detergent fibre (NDF), organic matter (OM) and organic matter digestibility (OMD) as g kg^{-1} of dry matter for experiment 1, 2002.

Factor	ADF	NDF	OM	OMD
Seed Source				
Ducks Unlimited	345	524 b	881 b	621
New Mexico	354	548 a	905 a	640
SE	8	9	7	15
Date of Clipping				
June	312 c	480 d	893 ab	699 a
July	337 bc	520 c	858 c	690 a
August	339 b	549 abc	886 b	683 a
September	349 b	536 bc	904 ab	609 b
October	365 ab	556 ab	907 ab	555 bc
November	383 a	574 a	911 a	548 c
SE	15	16	12	27

a - c Within the column numbers followed by a different letter are significantly different ($P < 0.05$) as determined by the Tukey's test.

Table 5.11: Seed Source x Clipping Date interaction means ($P < 0.05$) of organic matter (OM) and organic matter digestibility (OMD) as g kg^{-1} of dry matter for experiment 1, 2002.

Date of Clipping	Ducks Unlimited OM	New Mexico OM	Ducks Unlimited OMD	New Mexico OMD
	----------------------------------	g kg^{-1} DM	----------------------------------	
June	889 ab	896 ab	725 a	672 abcd
July	827 c	889 ab	684 abc	696 ab
August	879 b	893 ab	691 abc	675 abcd
September	895 ab	915 ab	607 cde	612 bcd
October	896 ab	918 a	520 ef	590 de
November	904 ab	919 a	498 f	597 cde
SE		8.2		33

a - e Within the two columns of a component numbers followed by a different letter are significantly different ($P < 0.05$) as determined by the Tukey's test.

Table 5.12: Acid detergent fibre (ADF), and neutral detergent fibre (NDF) for seed source factor for second (experiment 2) and third (experiment 1) year of growth harvested in 2003.

	2nd Year Growth		**3rd Year Growth**	
Factor	**ADF**	**NDF**	**ADF**	**NDF**
	------------------------------**g kg $^{-1}$ DM**------------------------------			
Seed Source				
DU	320 a	513 a	352 a	547 a
NM	309 b	499 b	332 b	529 b
SE	5.3	8.9	7.1	10.1

a - b Within a column numbers followed by a different letter are significantly different (P < 0.05) for the column as determined by the Tukey's test .

Table 5.13: Acid detergent fibre (ADF), and neutral detergent fibre (NDF) means for Clipping Date X Seed Source interaction ($P < 0.05$) and fertilizer factors separated out by seed source for second (experiment 2) and third (site 3) year of growth harvested in 2003.

	2nd Year Growth				**3rd Year Growth**			
Factor	**ADF**		**NDF**		**ADF**		**NDF**	
	DU	NM	DU	NM	DU	NM	DU	NM
	-----------------------	-----------------------	-----------------------	-------g kg^{-1}	DM-------	-----------------------	-----------------------	-----------------------
Clip Date								
June	303 a	----	480 b	----	328 a	259 b	522 b	454 c
July	321 a	294 b	514 a	457 b	349 a	349 a	554 ab	559 ab
Aug	314 a	343 a	510 a	542 a	366 a	360 a	569 ab	578 a
Sept	336 a	304 a	528 a	504 ab	353 a	311 ab	553 ab	530 abc
Oct	326 a	286 b	516 a	489 b	362 a	360 a	539 ab	565 ab
SE	11.7		16.1		10.8		13	
Fertilizer								
Fertilized	324	301	519 A	500	350	328	544	526
Non-fertilized	316	316	507 B	497	353	336	551	531
SE	1.7	1.4	2.3	6.8	2.4	4	3.3	5.5

a - c Within the two columns under a composition factor for clip date numbers followed by a different letter are significantly different ($P < 0.05$) for the interaction as determined by the Tukey's test.

A - B Within a column for fertilizer factors separated out by seed source numbers followed by a different letter in single column are significantly different ($P < 0.05$) as determined by the Tukey's test.

Table 5.14: Organic matter (OM), and digestible organic matter (OMD) for seed source factor for second (experiment 2) and third (site 3) year of growth harvested in 2003.

	2nd Year Growth		3rd Year Growth	
Factor	**OM**	**OMD**	**OM**	**OMD**
	---------- $g\ kg^{-1}$ DM ----------			
Seed Source				
DU	863	640	882 b	551 b
NM	891	643	910 a	594 a
SE	6.6	8.9	15.8	10.1

a - b Within a column numbers followed by a different letter are significantly different ($P < 0.05$) as determined by the Tukey's test .

Table 5.15: Organic matter (OM), and digestible organic matter (OMD) means for clipping date by seed source interaction (P < 0.05) and fertilizer factors separated out by seed source for second (experiment 2) and third (site 3) year of growth harvested in 2003.

	2nd Year Growth				3rd Year Growth			
	OM		OMD		OM		OMD	
Factor	**DU**	**NM**	**DU**	**NM**	**DU**	**NM**	**DU**	**NM**
Clipping Date			----------------	g kg $^{-1}$ DM	----------------			
June	883 ab	----	667 abc	-----	879 c	879 abcd	574 abc	643 a
July	858 bc	908 a	648 abc	670 abc	902 abc	917 ab	569 abc	601 ab
August	860 b	879 b	640 bc	589 c	898 abc	913 a	544 bc	574 abc
September	877 ab	883 ab	622 c	638 abc	887 bc	901 abc	545 bc	590 abc
October	836 c	902 a	622 c	707 a	843 d	920 a	520 c	564 abc
SE	0.7		15.4		7.2		16	
Fertilizer								
Fertilized	866	890	644	651	875 B	911	547	605
Non-fertilized	859	891	635	636	888 A	909	556	580
SE	7.1	5.9	9.7	9.8	5.3	3.2	9.8	12.4

a- c Within the two columns under a composition factor for clip date numbers followed by a different letter are significantly different (P < 0.05) for the interaction as determined by the Tukey's test.
A - B Within a column for fertilizer factors separated out by seed source numbers followed by a different letter in single column are significantly different (P < 0.05) as determined by the Tukey's test.

0.05) which was likely due to increased lignin. The NM plant secondary branch diameters were also negatively correlated with OMD ($P < 0.05$) (Table A7). The NM three year old plants continued to increase ($P < 0.05$) in OM until the October clipping date. Fertilizer had only a negative impact ($P < 0.05$) on the concentration of organic matter of three year old DU plants.

5.3.3 Ducks Unlimited Winterfat Leaves and Stems

The organic matter in the leaf material for 2002 plants remained relatively unchanged while organic matter digestibility declined ($P < 0.05$) (Table 5.16). Both ADF and NDF increased ($P < 0.05$) as the plants matured while crude protein and phosphorous declined ($P < 0.05$), which is a trend for plants in general (Cook 1972). The stems declined in digestibility more rapidly than the leaves (30% more). Fibre concentrations peaked in July for stems but peaked in October for leaves. Fibre concentrations increased but peaked in July when the plants had reached full flower and no further growth occurred (see chapter 3). Crude protein was lower in the stems but declined less rapidly than in leaves. Phosphorous declined at roughly the same rate for both leaves and stems.

In 2003 (Table 5.17), organic matter digestibilities for leaves declined more rapidly than the stems. Fibre accumulation tended to continue until the October clipping date but no significant increase ($P > 0.05$) occurred after the July clipping date. Stem tissue accumulated more fibre although at a slower rate than the leaves. Continued fibre and organic matter accumulation until the October clipping date suggests the plants were still growing. Stem crude protein declined from June to October by 36% while that of leaves declined by 51%. Phosphorous concentration declined at the same rate for stem and leaves and this was similar to the previous year's results.

Leaves have overall better nutritional qualities, with greater amounts of soluble carbohydrates contained within cells and cell walls (Van Soest 1994), but in this study winterfat leaves lost these qualities at a greater rate than stems. The difference between years can be attributed to the differences in meteorological conditions (see chapter 3). The wet, cool 2002 could have resulted in slower growth and less immediate

Table 5.16: Organic matter (OM), organic matter digestibility (OMD), acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein (CP) and total phosphorous (P) content for leaf and stem tissue of DU plants 2 years old (experiment 2). No significant (P > 0.05) fertilizer effect was observed.

	Leaf						**Stem**					
	OM	OMD	ADF	NDF	CP	P	OM	OMD	ADF	NDF	CP	P
	g kg^{-1} DM											
Date												
June	887	772 a	226 b	333 c	198 a	4 a	903 d	674 a	386 a	537 b	138 a	4 a
July	883	748 ab	283 a	418 b	155 b	3 b	918 c	443 b	486 ab	683 a	99 b	3 b
Aug	868	742 abc	286 a	441 ab	127 bc	2 c	924 bc	442 b	473 ab	644 a	93 b	2 c
Sept	894	728 bc	287 a	464 a	130 b	2 c	932 ab	418 b	449 b	611 ab	83 b	2 c
Oct	881	709 c	292 a	466 ab	90 c	1 c	939 a	400 b	386 c	666 a	77 b	1 c
SE	13	15.7	17.5	33.1	27.8	0.6	6.6	87.7	30.9	49	18.8	0.9

a - c Within the column numbers followed by a different letter are statistically significant (P < 0.05) as determined by Tukey's test.

Table 5.17: Organic matter (OM), organic matter digestibility (OMD), acid detergent fibre (ADF), neutral detergent fibre (NDF), crude protein (CP) and total phosphorous (P) content for leaf and stem tissue of DU plants 3 years old (experiment 1). No significant (P > 0.05) fertilizer effect was noted.

	Leaf						Stem					
	OM	OMD	ADF	NDF	CP	P	OM	OMD	ADF	NDF	CP	P
	---g kg^{-1} DM---											
Date												
June	890 ab	774 a	227 b	354 b	193 a	3.a	932 b	540 a	454 c	626 b	105 a	4 a
July	912 a	730 ab	284 a	451 a	155 ab	2 b	934 b	408 a	501 a	674 b	86 b	3 b
Aug	900 ab	690 bc	281 a	450 a	138 bc	2 bc	936 b	381b	498 ab	681 ab	85 b	2 c
Sept	895 ab	705 b	271 a	432 a	146 b	1 c	937 b	400 ab	480 b	641 b	84 b	1 d
Oct	864 b	654 c	288 a	461 a	95 c	1 d	944 a	319 c	521 a	703 a	68 c	1 d
SE	12.7	30.2	19.2	33.5	25.8	0.4	6.6	55.2	24.4	28.3	9.7	0.8

a - cWithin the column numbers followed by a different letter are statistically significant (P < 0.05) as determined by Tukey's test.

requirement for structural carbohydrates. The hot, dry 2003 could have resulted in dessication of leaf material and a loss of soluble carbohydrates (Wilson 1982).

5.4 Conclusions

The mineral profiles of the DU and NM winterfat plants were different. Crude protein, Mn, K, and S for both 2nd and 3rd year of growth and DU and NM plants in 2003 fall period, met the nutritional requirements of a replacement Angus heifer in the first trimester. Plants experiencing only their 1st year of harvest also met the requirements for P. New Mexico plants met the Fe requirements. Magnesium was in excess for both DU and NM plants but Fe was in excess only in DU plants. For these minerals that are in excess of animal requirements, dilution with other species with lower concentrations should be considered. Another source for Ca, Cu, Co and Se for both ages of plant as well as Zn for older New Mexico plants and for both ages of DU plants should be considered to meet the nutritional needs of livestock. Again, additional species in the plant community mix may be used to provide additional sources or mineral supplementation may be used if winterfat is to be used in monoculture. Boron, Mo, and Cd concentrations were not toxic.

Fibre content, organic matter and digestibility differed between the plant types with NM having a better nutritional profile. This is related mainly to the inability of the NM plant type to progress to seed set. Failure to reach the seed-set growth stage also played a role in the NM plants' mineral content. The result was two plant types with distinctive nutritional profiles as determined by chemical analysis when grown in Saskatchewan. The nutritional profiles require testing with animals to determine if the chemical differences will affect utilization and production. Additional germplasm screening could result in additional winterfat material having different mineral profiles with better survival rates in the northern portion of the winterfat range of adaptation.

Digestibility declined as plants aged which was evident with 2 year old plants being more digestible than 3 year old plants. Hot dry conditions (2003) likely decreased digestibility compared to wet cool conditions (2002).

Leaves for the DU plants were of better nutritional quality than the stems. The climate in which they grew had a greater impact on 1) fibre accumulation - for example stems accumulated fibre at a slower rate than leaves in a hot dry year; and 2) crude protein decline - for example stem crude protein declined at a slower rate than that of leaves in a hot dry year. Stem material also retained a greater proportion of its original crude protein value. This may partially explain the maintenance of nutritionally beneficial levels of crude protein in winterfat during the fall.

CHAPTER 6

WINTERFAT, ALFALFA AND WESTERN WHEATGRASS SEED MIX POTENTIAL

6.1 Introduction

Sustainability and the cost of livestock production during the fall and winter months in the Northern Great Plains can be improved by maintaining animals in the pasture compared with placing them in feedlots (Heitschmidt et al. 1996). Energy costs were lower when cattle instead of machinery were used to harvest the forage. In New Zealand, Waghorn and Woodward (2004) reported higher levels of greenhouse gas production from feedlots compared to pastoral systems. Cohen et al. (2004) found that feeding cattle on pasture to slaughter (pasture finishing) would reduce total methane emissions and increase the efficiency of feed conversion to liveweight gain when compared to backgrounding on pasture and then feeding to finish in a feedlot. Adams et al. (1996) indicated extension of the grazing season into the fall to early winter period will reduce costs and increase net returns to the beef producer. Jensen et al. (2002) recommended that shrubs and forbs could provide a protein source for fall grazing and thus reduce the cost of beef production.

Species mixtures usually produce more and provide a more stable biomass production over time than monocultures (Christian 1987; McNaughton 1993; Tilman et al. 1996; Chapin et al. 2000). Seeded forage mixtures with multiple functional groups have been proposed as a means to optimize livestock production on pasture (Masters 2002; Norman et al. 2002; Suszkiw 2004). Ideally the forage stand should provide both energy and protein as required by livestock and also be self sustaining. Dietary energy sources include plant fats, protein and carbohydrates. Carbohydrates are considered the most readily and economically available energy source for ruminant animals on pasture (Crampton and Harris 1969). The energy and protein sources also should be available in a synchronized manner (Orskov 1992). Animals grazing dormant tallgrass prairie required a balance of degradable intake protein in relation to digestible energy for optimal live weight gain (Bodine and Purvis 2003). Lintzenich et al. (1995) concluded that high-protein alfalfa (*Medicago sativa*) supplements greatly increased utilization of low-quality and high-fibre forage by grazing beef cattle. Bohnert et al. (2002) suggested that rumen-undegradable crude protein in the range of 20 to 60% can be effectively used by beef cattle consuming low-quality forage.

There are divergent points of view about the number of species required for an appropriate plant community mix. Co-existence of species in herbaceous vegetation requires the absence of factors that permit the expression of dominance, such as grazing that may favour some species but not others (Grime 2002). Pendery and Provenza (1987) concluded that interspecific competition among *Artemisia tridentata*, *Kochia prostrata*, and *Atriplex canescens,* in alfalfa and crested wheatgrass (*Agropyron desertorum* (Fisch. Ex Link) Schultes) stands had greater impact on species survival than grazing practices. Results from Colorado (Bonham and Mack 1987; Mack and Bonham 1988; Bonham and Mack 1990) suggested that western wheatgrass (*Pascopyron smithii*) and winterfat (*Krascheninnikovia lanata*) would make a compatible revegetation species mix based on their respective abilities to alter resource pools to their mutual benefit. Goeble and Cook (1960) classified winterfat as a good quality forage and western wheatgrass as fair. Rasmussen and Brotherson (1986) suggested a slower growing Indian rice grass (*Oryzopsis hymenoides*) would be a good companion grass for winterfat. Schellenberg and Banerjee (2002) found in a greenhouse study that alfalfa mixtures with winterfat or *Atriplex gardeneri* produced greater biomass than monoculture alfalfa. Including alfalfa in seeded hay and pasture mixes can elevate forage production by a 100% or more (Leyshon 1978; Kreuger and Vigil 1979), with attendant gains in livestock production (Hervey 1960; Kreuger and Vigil 1979). Kopp et al. (2003) found incorporating alfalfa in meadow brome (*Bromus bieberstenii*) pastures improved carrying capacity 28% , met nutritional requirements of lactating beef cows, did not entail financial risk and was always a cost-effective treatment compared to fertilized grass pastures in the study at

Brandon, MB. Campbell et al. (2004) noted interseeding of alfalfa (*M. falcata*) with native grasses increased the rate of below-ground carbon accumulation with benefits for both producers and the global climate compared native grasses grown without alfalfa.

Extension of grazing into the fall season requires adequate dietary energy and protein during a period when most plants are dormant. Winterfat, a native semi-shrub, has been noted for its good fall crude protein value (Sampson 1924; Reidl et al. 1964; Smoliak and Bezeau 1967; Abouguendia 1998). Jefferson et al. (2004) found western wheatgrass also to have sufficient crude protein for the needs of a medium frame British breed cow in its first trimester of gestation. Researchers in Utah (McKell et al. 1990; Otsyina et al. 1982) used winterfat to improve protein value of crested wheatgrass pastures during the fall. Arthun et al. (1988) found a trend to improved nitrogen balance within the animal when shrub and forb leaves were added to a grass hay diet. Nunez-Hernandez et al. (1989) found that mixtures containing winterfat supported intake and retention values equal or superior to that of alfalfa hay for goats. Otsyina et al. (1982) found 69% winterfat content in the diet was required to meet gross energy requirements for sheep grazing dormant crested wheatgrass.

In semiarid regions of the Canadian prairies, winterfat and western wheatgrass can be found in native range. Winterfat seed is available for purchase with the most commonly available seed being hand collected native seed from New Mexico. Past research had not indicated problems with adaptation of New Mexico seed in the environment in which this study was run (Schellenberg 2002). Western wheatgrass is known to be a dominant of semiarid Canadian prairie (Willms and Jefferson 1993).Western wheatgrass seed is easily available and at a reasonable cost. Choice of legumes is limited due low availability of native species combined with high cost and adaptability. Presently, the most cost-effective and easily available legume species adapted to the semiarid region is alfalfa.

The objective for the study was to determine which mix of winterfat, alfalfa and western wheatgrass would result in a stable plant community mix when defoliated in fall and also provide adequate nutritional value to support a British medium-framed breed heifer in its first trimester.

6.2 Materials and Methods

A complete randomized block design experiment with four replicates (Figure A5) was established in 2001 at the Semiarid Prairie Agricultural Research Centre at Swift Current, Saskatchewan (50° 17′ N, 107° 41′ W; elevation 825 m) on a Swinton loam soil (Orthic Brown Chernozem) (Ayres et al. 1985). A second site was attempted at the Semiarid Prairie Agricultural Research Centre at Swift Current, Saskatchewan on an alluvial Rego Chernozem (clay to clay loam) in 2002 (Ayres et al. 1985). Due to the seeded species being overwhelmed by weeds during the establishment year the second site was abandoned.

In 2002, the first site had plots divided into quarters to allow for comparison of weeds present versus no weeds. One quarter was randomly selected for hand weeding and the other three quarters were not weeded. Weeding occurred once in mid-July in 2002 and repeated in 2003. Only a quarter of the original plot was hand weeded to save on labour and time. Under the dry condition of 2001 weeds did not provide excess shading but under the wet conditions of 2002 weeds they did.

The experimental design from 2002 onward was a split plot design. The main plot treatments were the seed mix treatments that were seeded in 2001 (by number of pure live seeds: 5% winterfat/ 20% alfalfa/ 75 % western wheatgrass; 10% winterfat/ 40% alfalfa/ 50 % western wheatgrass; 20% winterfat/ 40% alfalfa/ 40 % western wheatgrass; 40 % winterfat/ 40% alfalfa/ 20 % western wheatgrass). The mixtures were selected to provide a constant alfalfa content with winterfat increasing as western wheatgrass decreased. The changing winterfat and western wheatgrass proportions allowed comparisons of their contribution to seeded plant community makeup, physically and nutritionally. The subplot factor was absence or presence of weeds. Data collection occurred in one weeded quarter and one unweeded quarter.

Western wheatgrass (cv Walsh) and alfalfa (*Medicago falcata* cv MF3713) were seeded in the same row with a self-propelled press drill plot seeder (Dyck et al. 1993) with 30 cm row spacings. Winterfat seed (New Mexico hand collected seed (fall 2000) purchased from Wind River Seed due to lack of available DU seed) was broadcast seeded by hand the same day. The combined seeding rate of all three species was 300 live seeds per m^2. Plots (2 m x 8 m) were separated by a single row of streambank wheatgrass (*Elymus lanceolatus* (Scribn. & Sm.) cv Streambank).

In October 2001, plant composition (% ground cover by species), canopy cover (total % ground cover) and bare ground (% ground not covered) were determined for two randomly selected 0.25 m^2 portions of each main plot and clipped to a height of 5 cm. In 2002 and 2003 clipping occurred also in late October on one randomly selected 0.25 m^2 area per subplot treatment. Species' composition, canopy cover and bare ground as described above and biomass were determined for each subplot. The late October sampling date provided an assessment of the potential plant species mix at the anticipated time of utilization. The clipped material was separated at the time of clipping into seeded species and weeds. All clipped material was dried in forced air (set at 60° C) ovens to a constant weight. Dry material was weighed for dry matter yield determination. Samples were then ground in a Wiley mill to pass through a 1 mm screen, labelled and placed in glass jars. Samples were analysed for *in vitro* organic matter digestibility (OMD) and organic matter (OM) (Tilley and Terry (1963) as modified by Troelsen and Hanel (1966)); acid detergent fibre (ADF) and neutral detergent fibre (NDF)(Goering and Van Soest 1970); nitrogen (AOAC 1984) and converted to crude protein (CP) by multiplying by 6.25; and phosphorous (P) after digestion with sulphuric acid (Kalra 1998). ADF and NDF were determined for seeded species only while the rest of the chemical analyses were also determined for weeds. At least one sample for every subplot was analysed.

All plots were mowed to a uniform height of 5 cm after sample collection to ensure uniformity within the plots, ie. to prevent snow trapping in clipped or unclipped areas.

Daily mean temperatures, precipitation and potential evaporation (US Weather Bureau Class A pan) were obtained from the weather station approximately 1 km away.

For 2001, data were statistically analysed using ANOVA by individual years using Proc GLM (SAS Institute, Inc. 1999) and standard errors (SE) calculated (Steel and Torrie 1980). When a factor was significant, $P < 0.05$, Tukey's test was used to calculate mean separation (Steel and Torrie 1980). For 2002 and 2003, Proc Mixed repeated measures (SAS Institute, Inc. 1999) with Satterthwaite calculation for F-test (Steel and Torrie 1980) was utilized for data analyses to assess differences between years and within years. The 2001 data was not included in the Proc Mix analysis because of the change in statistical design from 2001 to 2002. Appropriate covariance structure was selected (variance components (Simple), constant correlation (CS), first-order autoregressive covariance (AR(1)), first-order ante dependence covariance (ANTE(1)), and unstructured covariance (UN)) using criteria described by Littell et al. (1996) and Wang and Goonewardene (2004). When the seed mixture was significant ($P < 0.05$) orthogonal polynomials were used to determine the nature of the response curve (Steel and Torrie 1980). Orthogonal polynomials were used because of the step-wise increments in the winterfat and western wheatgrass content of the seed mixtures used in the experiment. Comparisons of means for weed effects within years were performed for significant ($P < 0.05$) year by weed interactions using orthogonal contrasts (Steel and Torrie 1980).

6.3 Results and Discussion

Only the year by weed interaction was found to be significant ($P < 0.05$) for weed DM, weed cover, bare ground cover, ADF of seeded species and NDF of seeded species.

6.3.1 Dry Matter Yield and Species Composition of Mixtures

In the establishment year (2001) the mixtures were not different ($P > 0.05$) (Table A8) for dry matter yields. Canopy cover, and species composition (Table A9) also were not ($P > 0.05$) different between seed mixes. Canopy cover and amount of winterfat, although not different ($P > 0.05$), tended to increase as winterfat content of the seed mix increased. Western wheatgrass composition and bare ground, although not different (P > 0.05), tended to decrease with increasing winterfat seed content while alfalfa composition remained constant over the range of seed proportions in mixtures. The dominant weeds were Russian thistle (*Salsola kali* L.), prostrate pigweed (*Amaranthus graecizans* L.) and wild tomato (*Solanum triflorum* Nutt.).

For years 2002 and 2003 the results were combined for mixed model statistical analysis. For the yield data, first-order auto-regression covariance structure was used (Table A10) indicating that a covariance existed between years. This result is similar to observations in wheat in which a relationship existed in space (Clarke et al. 1994). Western wheatgrass composition and weed cover indicated that a covariance existed also between years. In the case of western wheatgrass, this may have been due to increasing numbers of western wheatgrass plants due to its rhizomatous nature. Canopy cover, bare ground cover, winterfat and alfalfa species compositions were found to fit a variance component covariance structure (simple covariance structure) "which assumes that all observations are independent of each other and there is no correlation (covariance) between any pair of observations, even between the repeated measures on the same subject"(Wang and Goonewardene 2004).

After 2001, dry matter production (Table 6.1) was different (P < 0.05) between years with seeded species contributing a greater amount in 2003 while the weed contribution declined. Weeding had no effect on the seeded species but reduced (P < 0.05) the weed dry matter yields by 70% resulting in a 20% reduction in total dry matter yield. No trends in seed mixture contribution were noted for biomass. Canopy cover increased from 2002 to 2003 while bare ground cover did not change (Table 6.2). Winterfat contribution to biomass declined by 77% from 2002 to 2003. Potential reasons for the decline are: 1) poor persistence of New Mexico sourced seed (see chapter 3), 2) removal of plant material in excess of the recommended 50% (Fetcher 1981) resulting in excess utilization of winterfat's carbohydrate reserves to which the plant is sensitive (Williams 1985), and 3) competition from the other species within the mix, specifically grass, as also reported by Chambers and Norton (1993). All three factors may have been

Table 6.1: Dry matter (DM) yield for seeded, weed and total species of main factors (year, weeds, and seed mix (winterfat(WF), alfalfa (A), western wheatgrass (G))) for combined years 2002 and 2003. Interactions were not significant ($P > 0.05$) except for weed DM.

Main Factor	Seeded DM	Weed DM	Total DM
Year	---------- $g\ m^{-2}$ ----------		
2002	53.8 b	88.6 a	141.2 b
2003	232.3 a	27.5 b	256.8 a
SE	38.2	30.4	27.6
Weeds			
Present	150.0	89.2 a	222.5 a
Removed	136.0	26.8 b	176.0 b
SE	28.0	6.8	21.2
Seed Mix			
5%WF/20%A/75%G	159.4	52.4	212.0
10%WF/40%A/ 50%G	151.8	46.4	186.4
20%WF/40%A/ 40%G	118.7	62.0	187.2
40%WF/40%A/ 20%G	142.2	71.6	210.4
SE	54.4	10.8	39.2

a - b Numbers within column followed by different letter are statistically different ($P < 0.05$)

Table 6.2: Canopy cover, bare ground, winterfat (WF), alfalfa (A), western wheatgrass (G) and weed composition of main factors (year, weeds, and seed mix) for combined years 2002 and 2003. Interactions were not significant (P > 0.05) except for weed x year for weeds and bare ground.

Main Factor	Canopy Cover	Bare Ground	WF	A	G	Weed
Year			%			
2002	72.7 b	19.1	12.3a	16.4	15.0 b	29.8a
2003	80.9 a	11.0	2.8 b	20.2	39.8 a	18.3 b
SE	2.1	1.7	9.3	2.3	3.8	4.6
Weeds						
Present	79.1	15.8	6.2 b	17.5	27.3	24.7
Removed	74.5	14.3	8.9 a	19.0	27.5	23.4
SE	2.1	1.7	9.3	2.3	3.2	3.7
Seed Mix						
5%WF/20 %A/75%G	79.5	15.0	4.2	13.6	36.8	23.3
10%WF/40 %A/50%G	69.0	18.3	5.4	16.2	32.9	16.5
20%WF/40 %A/40%G	78.8	14.7	6.5	20.5	25.0	26.6
40%WF/40 %A/20%G	79.8	12.2	14.1	22.8	14.8	29.8
SE	3.0	2.4	1.3	3.2	5.3	6.5
Orthogonal polynomial probabilities for seed mixture						
Linear	ns	ns	< 0.01	ns	0.01	ns
Quadratic	ns	ns	0.02	ns	ns	ns
Cubic	0.03	ns	ns	ns	ns	ns

a - b Numbers within column followed by different letter are statistically different (P < 0.05).

ns - not significant (P > 0.05) for values within column.

important but evidence for the importance of increased competition was supported by the increased western wheatgrass composition, from 15 to 40%, a 2.7 fold increase. Wheatgrasses as a group are known to be highly competitive (Hammermeister and Naeth 1999) and western wheatgrass has been observed to be invasive (personal observation, unpublished data). Rasmussen and Brotherson (1986) suggested a slower growing and less competitive grass such as Indian ricegrass (*Oryzopsis hymenoides*) would make a compatible species mix, in contrast to reports that winterfat and western wheatgrass would be compatible (Bonham and Mack 1987; Mack and Bonham 1988; Bonham and Mack 1990). The suggestion of using a slower growing grass or less competitive grass in winterfat mixtures needs to be investigated. Pendery and Provenza (1987) found that interspecific competition was more important than grazing management when planting winterfat within a crested wheatgrass sward. The co-existence of herbaceous vegetation depends on minimizing interspecies competition and limiting dominance expression (Grime 2002).

The reduction in weeds composition from 2002 to 2003 indicated an increase in dominance of the perennial seed mix. In 2002, the dominant weeds were kochia (*Kochia scoparia*) and narrow leaf goosefoot (*Chenopodium leptophyllum* (Mog.) Nutt. Ex S. Wats.) while in 2003 the dominant species were kochia, flixweed (*Descurainia sophiodes* (L.) Webb ex Prantl) and crested wheatgrass (*Agropyron cristatum* (L.) Gaertn.).

The seed mix factor had a cubic effect ($P < 0.05$) on canopy cover while both winterfat and western wheatgrass composition had a linear effect ($P < 0.05$). Winterfat composition increased with increased proportion in the seed mix while western wheatgrass declined linearly with decreased proportion in the seed mix.

6.3.2 Chemical Analyses of Seed Mixtures

Mixed model statistical analyses of chemical data indicated that most measured parameters fit the variance components structure (Table A9), indicating no covariance relationship between or within years. The exceptions were crude protein and total P for seeded species which fit the first-order autoregressive covariance structure, which indicated a covariance relationship with the previous year. The relationship identified the impact that the years' weather and plant community evolution impact may have on nutritional makeup of the plant mixes. Lower crude protein and lower P concentrations were found in the plant mixes (Table 6.4) due to hot, dry conditions combined with increased western wheatgrass in 2003.

Fibre (ADF and NDF) and organic matter for the seeded species increased ($P < 0.05$) in 2003 compared with 2002 (Table 6.3). Organic matter digestibility was greater ($P < 0.05$) in 2002 than in 2003. Under hot dry conditions, such as those encountered in 2003, less leaf material is produced resulting in increased stem proportion and therefore increased fibre and decreased digestibility (Minson 1990). Organic matter increased in 2003, as did fibre concentrations. The weed component did not differ in organic matter or digestibility between 2002 and 2003. In the unweeded treatments fibre and organic matter increased while digestibility decreased for seeded species. Shading from the fast-growing annual weeds along with a cooler environment results in more fibrous plants with decreased digestibility (Wilson 1982). This phytochrome response (Casal and Smith 1989) may have been a result of the changing light environment caused by neighbouring competitor plants (Casal et al. 1990) resulting in etiolation (Salisbury and Ross 1985; Fitter and Hay 1989). The OM and OMD of weed species were not ($P > 0.05$) affected by removal of weeds, year, nor seed mixture. Organic matter and ADF concentration responded in a linear fashion to increasing winterfat content. Winterfat would be expected to contribute more fibre or lignified material to the forage mixture because it is a shrub. However, OMD and NDF did not differ between seed mixes. The lack of differences may have been in part due to the decreased amount of winterfat from 2002 to 2003 which resulted in increased contributions of alfalfa and western wheatgrass to the mix.

Crude protein and total phosphorous concentrations were higher ($P < 0.05$) for seeded species and weeds in 2002 compared to 2003 (Table 6.4). Water stress, as encountered in 2003, could be a contributory factor to low protein content (Jones and Wilson 1987) for both seeded and weed species. Additional soil water might increase

Table 6.3: ADF, NDF, OM and OMD of main factors (year, weeds, and seed mix) for combined years 2002 and 2003. Interactions were not significant (P > 0.05) except year by weed for ADF and NDF.

Main Factor	ADF of Seeded Species	NDF of Seeded Species	OM of Seeded	OM of Weeds	OMD of Seeded Species	OMD of Weeds
Year	----------	----------	---------- g kg^{-1} DM	----------	----------	----------
2002	333 b	507 b	905 b	866	582 a	487
2003	355 a	558 a	921 a	904	519 b	543
SE	4.2	7.8	1.9	33.0	3.8	39.0
Weeds						
Present	364 a	556 a	916 a	900	540 b	496
Removed	324 b	509 b	911 b	834	561 a	514
SE	4.2	7.0	1.4	33.0	3.9	39.0
Seed Mix						
5%WF/20%A/75%G	334	535	907	904	554	497
10%WF/40%A/50%G	336	538	911	891	554	501
20%WF/40%A/40%G	352	534	920	866	539	516
40%WF/40%A/20%G	353	522	915	880	554	491
SE	7.8	43.0	20.0	40.7	5.6	48.0
Orthogonal polynomials probabilities for seed mixture						
Linear	0.01	ns	< 0.01	ns	ns	ns
Quadratic	ns	ns	0.02	ns	ns	ns
Cubic	ns	ns	0.03	ns	ns	ns

a - b Numbers within column followed by different letter are statistically different (P < 0.05)

ns - not significant (P > 0.05) for values within column

Table 6.4: Crude protein (CP) and total phosphorous (P) of main factors (year, weeds, and seed mix) for combined years 2002 and 2003. Interactions were not significant ($P > 0.05$).

Main Factor	CP Seeded species	CP Weeds	P Seeded species	P Weeds
Year	----------	g kg^{-1} DM	----------	
2002	114 a	116 a	1.5 a	2.2 a
2003	79 b	74 b	0.9 b	1.1 b
SE	2.1	4.0	0.03	0.08
Weeds				
Present	92 b	84 b	1.2	1.5
Removed	101 a	106 a	1.2	1.8
SE	2.0	3.5	0.04	0.08
Seed Mix				
5%WF/20%A /75%G	95	91	1.2	1.5
10%WF/40%A /50%G	96	94	1.2	1.8
20%WF/40%A /40%G	95	98	1.1	1.7
40%WF/40%A /20%G	100	96	1.2	1.7
SE	3.0	5.2	0.05	0.12

a - b Numbers within column followed by different letter are statistically different ($P < 0.05$)

availability and possibly the uptake of phosphorous compared to drought stressed plants therefore resulting in higher total P levels. Removal of weeds decreased light competition for seeded plants decreased phytochrome response and decreased fibre for structural growth. This resulted in more leaf and less stem and greater crude protein. The seed mixes were not different ($P > 0.05$) in crude protein or total phosphorous. The crude protein levels were sufficient for a medium framed British breed cow in its first trimester (Table A6) but deficient in phosphorous (NRC 2000).

Addition of forbs and shrubs is a well-documented means of increasing nitrogen levels of low quality forage (Sampson 1924; Otsinya 1984; Jones and Wilson 1987; Arthun et al. 1992b; Rafique et al. 1992; Vallentine 2001). Most grasses are deficient in N or crude protein in fall (Clarke and Tisdale 1945; McLean and Tisdale 1960; Smoliak and Bezeau 1967; Cook 1972; Jefferson et al. 2004) and low in nutritive value (Bezeau and Johnston 1962). Jefferson et al. (2004) noted that western wheatgrass had a crude protein level of 66 g kg^{-1} DM compared to 95 to 100 g kg^{-1} DM observed for the four seed mixes. The addition of alfalfa and winterfat to the mix may have improved the plnt communities crude protein concentration and further research is required to determine their individual contributions.

The low total P could lead to reduced feed intake, pica, reduced rates of gain, low conception rates, reduced milk production, poor appearance and rickets (Kincaid 1988). The impacts of P deficiency are difficult to detect due to non-specificity and are often confounded by concurrent low energy intakes (Cohen 1980).

6.3.3 Year by Weed Interactions

Non-removal compared to a one time removal of weeds resulted in decreased ($P < 0.05$) DM yield, increased weed cover, canopy cover, bare ground, ADF of seeded species and NDF of seeded species regardless of the year (Table 6.5). Canopy cover differences between years indicated an increase in seeded species in the weeded portions of the plots. Tables 6.3 - 6.6 indicated that the effect of years was significant ($P < 0.05$) and may have been due to different meteorological conditions combined with evolution of seeded species mixtures.

Table 6.5: Year by weed interactions for weed DM, weed cover, bare ground cover, ADF of seeded species and NDF of seeded species that were statistically significant ($P < 0.05$).

	Weed DM ($g\ m^{-2}$)		Weed Cover (%)		Canopy Cover (%)		Bare Ground Cover (%)		ADF		NDF	
Factor	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003	2002	2003
Weeds									---------------- $g\ kg^{-1}$	--------------		
Removed	39.5	14.0	15.9	10.8	23.9	29.6*	55.6	17.6	303	346	472	546
Present	137.6*	40.8*	79.6*	38.4*	24.8	25.6	100.0*	70.4*	364*	364*	541*	571*
SE	10.8	8.0	21.2	20.4	3.0	3.0	9.6	9.6	5.9	5.9	9.0	9.2

* - ($P < 0.05$) within columns determined using orthogonal contrasts.

Weather conditions during the years of the study are described in chapter 3. In summary, the 2003 growing season was warm and dry but the 2002 season was cool and wet.

6.4 Conclusions

Increasing the winterfat component in the seed mix increased the amount of winterfat in the resulting plant community just as decreasing western wheatgrass decreased the contribution of western wheatgrass. Winterfat decreased from 2002 to 2003 indicating a potential persistence problem with the New Mexico seed source and increasing competition from western wheatgrass. Further research is required to examine the effect of using more persistent winterfat germplasm and less competitive grasses and/or altering other factors such as sequence of seeding.

The resulting plant communities from all four seed mixes had crude protein levels adequate for maintenance of a medium framed British breed cow in the first trimester of gestation. Total phosphorous concentrations, however, were below requirements.

The year of data collection had a major impact on chemical composition of the forage. The cool wet year of 2002 resulted in forage with lower fibre and organic matter concentrations with increased crude protein concentration and organic matter digestibility compared to the hot dry year of 2003. Competition from annual weeds resulted in forage with increased fibre and organic matter concentration with decreased digestibility and crude protein concentration compared to plots in which weed competition was reduced.

CHAPTER 7

DIGESTION KINETICS OF WINTERFAT, ALFALFA AND WESTERN WHEATGRASS AS MONO- AND POLY- CULTURE MIXES

7.1 Introduction

The sustainability and economics of livestock production during the fall and winter months in the Northern Great Plains can be optimized by maintaining animals on pasture compared to feedlots or other confinement systems (Heitschmidt et al. 1996). Energy costs were lower when cattle instead of machinery were used to harvest the forage. Waghorn and Woodward (2004) found that sustainability in New Zealand was reduced by the higher levels of greenhouse gas production in feedlots compared to pasture systems. Cohen et al. (2004) found that feeding cattle on pasture to slaughter weight would reduce total methane emissions and increase the efficiency of conversion of feed energy to liveweight gain when compared to backgrounding on pasture and finishing in a feedlot. Adams et al. (1996) indicated that extension of the grazing season into the fall and early winter reduced costs and increased net returns to the producer. Jensen et al. (2002) recommended the inclusion of shrubs and forbs in pastures to reduce the cost of fall grazing.

Seeded forage mixtures with multiple functional groups are seen as a means to optimize livestock production on pasture (Masters 2002; Norman et al. 2002; Suszkiw 2004). Ideally the forage stand should provide energy, protein and be self-sustaining. Dietary energy sources include plant fats, protein and carbohydrates. Carbohydrates are considered the most available and economical, energy source for ruminant animals on pasture (Crampton and Harris 1969). Energy and protein sources should be available in a synchronized manner (Orskov 1992). Animals grazing dormant tallgrass prairie required a balanced diet of degradable intake protein in relation to dietary total digestible nutrients for optimal live weight gain (Bodine and Purvis 2003). Lintzenich et al. (1995)

concluded that inclusion of high protein alfalfa supplements greatly increased utilization of low quality high fibre forage by grazing beef cattle. Bohnert et al. (2002) suggested that an undegradable crude protein intake in the range of 20 to 60% can be effectively used by beef cattle consuming low-quality forage.

Mixtures are usually more productive and provide a more stable biomass over time (Christian 1987; McNaughton 1993; Tilman et al. 1996; Chapin et al. 2000). There are a number of differing opinions on what would make an appropriate plant community mix. Pendery and Provenza (1987) concluded that interspecific competition had a greater impact on shrub survival than modifying grazing management when *Artemisia tridentata*, *Kochia prostrata*, and *Atriplex canescens* were introduced into alfalfa and crested wheatgrass stands. Research from Colorado (Mack and Bonham 1988; Bonham and Mack 1987; Bonham and Mack 1990) suggested that western wheatgrass (*Pascopyrum smithii*) and winterfat (*Krascheninnikovia lanata* (Pursh) A.D.J. Meeuse & Smit) would make a compatible revegetation mix. Goeble and Cook (1960) classified winterfat as a good quality forage and western wheatgrass as fair. Rasmussen and Brotherson (1986) suggested a slower growing grass such as Indian rice grass (*Oryzopsis hymenoides*) would be a better companion grass for winterfat than more rapid growing grasses. Schellenberg and Banerjee (2002) found, in a greenhouse study, that shrub/alfalfa mixtures containing winterfat or *Atriplex gardeneri* produced more biomass, over seven harvests, compared to monoculture alfalfa (*Medicago sativa*). Including alfalfa in seeded hay and pasture mixes can elevate forage production by as much as 100% or more (Leyshon 1978; Kreuger and Vigil 1979), with attendant gains in livestock production (Hervey 1960; Kreuger and Vigil 1979). Kopp et al. (2003) found that alfalfa in mixture with meadow bromegrass (*Bromus biebersteinii*) pastures improved carrying capacity 28% , met nutritional requirements of lactating beef cows, did not entail financial risk and was always a cost-effective treatment compared to fertilized meadow bromegrass pastures in Brandon, Manitoba. Campbell et al. (2004) noted that interseeding of alfalfa (*Medicago falcata*) with native grasses increased the rate of belowground carbon accumulation which could be a benefit for both cattle producers and the global climate.

Extension of grazing into the fall season requires adequate dietary energy and protein during a period when most plants are dormant. Winterfat, a native semi-shrub, has been noted for its crude protein concentration in fall and winter (Sampson 1924; Reidl et al.1964; Smoliak and Bezeau 1967; Abouguendia 1998). Jefferson et al. (2004) found that western wheatgrass also had sufficient crude protein for the needs of a medium frame British breed cow in its first trimester of gestation. Researchers in Utah (Otsyina et al. 1982; McKell et al. 1990) used winterfat to improve protein value of crested wheatgrass pastures during the fall. Arthun et al. (1988) found a trend to improved nitrogen balance within the animal when shrub and forb leaves were added to a grass hay diet. Nunez-Hernandez et al. (1989) found that mixtures containing winterfat supported intake and retention values equal or superior to that of alfalfa hay for goats. Otsyina et al. (1982) found 69% winterfat content in the diet was required to meet gross energy requirements for sheep grazing dormant crested wheatgrass.

Within the distribution range winterfat is known to have developed ecotypes due to soil type (Workman and West 1969; Goodman 1973), and salinity (Clark and West 1971). Ecotypic differences can be noted as differences in productivity for fruit, seed characteristics, above-ground productivity and degree of tolerance of soil pH (Stevens et al. 1977). Stebbins (1950) defined ecotypes as a distinct genotypic response of a widespread species to a particular habitat. The response is not necessarily morphological in nature. Epstein (1972) suggested that the potential for nutritional ecotypes exist, which has not been previously reported for winterfat. Results in Chapter 5 suggest that nutritional ecotypes occur in winterfat.

In the end, the appropriate composition of a species mixture and its resultant nutritive value will depend on the nutritional requirements of the target animal (Mould 2003). Chemical analysis provides concentrations of specific components from which nutritive value is inferred. However, the *in sacco* technique has provided a substantial contribution to understanding ruminal digestion and allows for the identification of components (soluble fraction, and slightly soluble fraction) utilized by rumen microflora and post-ruminal (rumen undegradable fraction) usage by the animal (Mould 2003). Orskov and MacDonald (1979) first estimated the parameters using the Gauess-Newton method. There is no adequate substitute for the *in sacco* procedure to assess the rumen environment (Orskov 2000). In their review of the *in sacco* procedure, Huntington and Givens (1995) indicated that there was a lack of standardization. Vanzant et al. (1998) provided recommendations for standardization of the method.

Digestive kinetics information for widespread perennial forages utilized in the fall/winter period is lacking in the literature. Yu et al. (2004) noted that maturity had a significant impact on the digestive kinetics of alfalfa and timothy (*Phleum pratense*). No digestive kinetics information exists for novel forage shrub species such as winterfat.

The first objective of the following study was to provide information on the digestive kinetics of fall harvested alfalfa, western wheatgrass and two winterfat plant types utilizing beef steers as the model animal. The second objective was to determine the effect that plant species mixtures consisting of alfalfa, western wheatgrass and winterfat might have on digestive kinetics.

7.2 Materials and Methods

7.2.1 Sample Preparation

Winterfat forage from the DU and NM seed sources in November (2002), and the DU plant type in October 2003 were harvested from the experiment 1 described in chapter 3 (see Figure 2.1). Winterfat samples were random subsamples of biomass obtained from the experiment. Alfalfa, cv. Rangelander, and western wheatgrass, cv. Rodan, were harvested from adjacent plots within 2 weeks after winterfat harvest. New Mexico winterfat was vegetative while western wheatgrass, alfalfa and DU winterfat had completed their growth cycle and were fully mature. All samples were dried in forced air (set at 60°C) ovens to a constant weight. Dried samples were ground in a Wiley mill to pass through a 1-mm screen, labelled and placed in glass jars.

7.2.1.1 Mono-Culture Comparison, Experiment 1

The first experiment compared mono-cultures of western wheatgrass, alfalfa, and

New Mexico and DU winterfat material harvested in 2002.

7.2.1.2 Poly-Culture Comparison, Experiment 2

The second experiment was a poly-culture comparison of the mixtures (20%winterfat/30% alfalfa/50%western wheatgrass, 50%winterfat/30% alfalfa/20%western wheatgrass) which contained material combined by weight from the 2002 harvest for alfalfa and western wheatgrass. The source of winterfat for the mixture and for 100% winterfat comparison in this second experiment was DU material harvested in 2003. New Mexico material was not included because the number of samples would exceed the limit for the number of samples accommodated in the rumen (Vanzant et al 1998).

7.2.2 Animals and Diets

Three rumen-fistulated steers were used in accordance with the recommendations of Mehrez and Orskov (1977). The Angus/Hereford cross steers were fed, ad libitum, a maintenance diet of meadow bromegrass/alfalfa hay based on 3% of body weight. Water was always available. The animals used for these experiments were cared for under the guidelines as laid down by the Canadian Council on Animal Care (1993).

7.2.3 In Situ Rumen Incubation

Procedures closely followed recommendations of Vanzant et al. (1998). Samples (5 g) were randomly placed in numbered 10 x 20 cm bags of white polyester monofilament, nitrogen free with a 53 micron (± 10) pore size (ANKOM Company, Fairport, NY). The bags were tied approximately 2 cm below the top, with dental floss, allowing a 13.9 mg cm^{-2} sample to bag surface area ratio. Sample bags were placed in a lingerie bag, attached to a 50 cm cord, containing a 50 g weight to aid in retaining samples in the dorsal portion of the rumen. Incubations were performed according to the "gradual addition/all out" schedule. The rumen incubations were carried out for 72, 48, 36, 24, 12, 6, and 0 h; bags were inserted at 0900 h (day 1), 0900 h (day 2), 2100 h (day 2), 0900 h (day 3), 2100 h (day 3), and 0300 h on day 4. Bags were removed 0900 (day 4). Two samples of each feed were placed in the rumen for the 72, 48 and 36 h periods to insure sufficient material for post-incubation chemical analysis. Total number of sample bags in the rumen per run for the mono-culture feeds was 36 while total number of sample bags in the rumen per run for the poly-culture comparison was 45. Each determination was repeated twice.

The samples (including 0 h samples) were then rinsed five times with 45 L cold water using a domestic clothes washer (Kenmore) on delicate cycle with 1-min agitation and a 2-min spin per rinse cycle. All samples were dried in forced air ovens (set at 60°C) to a constant weight. The duplicate samples for 72, 48 and 36 h time were bulked for each time prior to chemical analysis. Both runs were processed for the mono- and poly-cultures in the laboratory at the same time to decrease potential variation due to lab analysis.

7.2.4 Chemical Analyses

Dry matter (DM) was determined by weighing dried samples. Nitrogen was determined by Kjeldahl digestion and distillation (AOAC 1984) and multiplied by 6.25 to provide crude protein (CP) concentrations. Neutral detergent fibre (NDF) content was obtained using the method described by Goering and Van Soest (1970). Residual (%) DM, CP, and NDF were calculated.

7.2.5 Model Fitting and Statistical Analysis

The rumen degradation characteristics included rapidly degradable fraction (Sf, %), which was washed out without rumen incubation, potentially degradable or slowly degradable fraction (D, %), which degraded exponentially, undegradable fraction (U, %), and the rate of degradation (K_d , % h^{-1}). The parameters were estimated using the software package Origin version 6 utilizing iterative least squares regression (Gauess-Newton method) by following the first-order kinetics equation (Orskov and MacDonald 1979):

$$R(t)\ (\%) = (100\text{-}Sf\text{-}D) + D^{*}\exp^{-K_d{}^{*}t} = U + D^{*}\exp^{-K_d{}^{*}t} \qquad (7.1)$$

where R(t) = residue (%) of the amount of incubated material after t hours of rumen incubation.

Effective degradability (ED, %) was calculated:

$$ED\ (\%) = Sf + D^{*}K_d / (K_d + K_p) \qquad (7.2)$$

where K_p is the passage rate and assumed to be 4 % h^{-1} for DM, CP and NDF. The rumen by-pass fraction or rumen undegradability (RU, %) was calculated using:

$$RU\ (\%) = U+D^*\ K_p = K_p\ /\ (Kd + K_p). \qquad (7.3)$$

A calculated ED was used for comparison with the observed ED (7.2) of the two - three species mixtures.

Calculated ED = (observed ED for G * % of G in mixture) + (observed ED for A * % of A in mixture) + (observed ED for WF * % of WF in mixture) (7.4)

Data that failed to converge after 200 iterations was removed from the data set prior to analysis of variance. Data were tested for fit to normal distribution using the Shapiro-Wilk test (SAS 1999). Using a complete randomized block design an analysis of variance, for main effects and all interactions, was done for K_d, ED, Sf, D, U, and RU using Proc GLM (SAS Institute, Inc. 1999). Standard error (SE) was calculated (Steel and Torrie 1980). When a factor was significant ($P < 0.05$) a Tukey's test was calculated for mean separation (Steel and Torrie 1980).

7.3 Results and Discussion

Pre-digestion chemical analysis (Table 7.1) indicated a low CP content for western wheatgrass. This value was much lower than the 66 g CP kg^{-1} DM reported for Swift Current, or any of the other sites reported by Jefferson et al. (2004). Jefferson et al.'s (2004) samples were harvested in September compared to November in this study. The later sampling date in this study may have contributed to lower crude protein and higher NDF. Alternatively lower CP and higher NDF concentrations could be due to cultivar differences or greater precipitation in 2002 (see Chapter 3) which would produce higher fibre production (Wilson 1982). Frank and Karn (1988) noted that the western wheatgrass cv Rodan had more stem DM than leaf DM when compared to cv Rosana which resulted in lower in vitro digestible organic matter. Alfalfa CP values were similar to winterfat values but NM winterfat tended to be closer to alfalfa than DU winterfat. The two species mixes were similar in CP and NDF concentrations.

The NDF concentration of NM winterfat tended to be closer to alfalfa than DU while the mixtures were similar to DU winterfat. Western wheatgrass NDF concentration was higher than the value reported by Jefferson et al. (2004) for Swift Current and other sites.

The Shapiro-Wilk goodness of fit test indicated the data were normally distributed.

7.3.1 Mono-Culture Comparison, Experiment 1

The run or replicate in time (T), the Steer (St) and Feed x Steer interaction were not statistically significant ($P > 0.05$) (Table A11) for any of the measured digestive kinetics of dry matter, and its NDF or crude protein components.

Degradation rate of the slowly degradable fraction of DM (Table 7.2) was similar for alfalfa and both winterfat seed sources, which in turn, were greater ($P < 0.05$) than that of western wheatgrass. The soluble fraction (Sf) of dry matter for DU winterfat was greater ($P < 0.05$) than the western wheatgrass while alfalfa and NM winterfat were intermediate ($P > 0.05$). The DU winterfat had a smaller concentration ($P < 0.05$) of the slowly

Table 7.1: Initial CP and NDF for bulk feed stuffs used in the *In Sacco* digestion comparisons.

Feed Stuff	CP	NDF
	---------- g kg^{-1} DM ----------	
100% Alfalfa (A)	186	554
100% Western wheatgrass (G)	37	688
100% DU winterfat 2002 (not used in mixtures)	95	632
100% DU winterfat 2003 (WF)	82	724
100% New Mexico winterfat (not used in mixtures)	134	592
20%G/30%A/50%WF	89	612
50%G/30%A/20%WF	85	651

Table 7.2: Effects of species (two winterfat plant types (DU, NM), western wheatgrass (G) and alfalfa (ALF)) on *in situ* rumen degradation characteristics (soluble fraction (Sf), slowly degradable fraction (D), degradation rate of D (K_d), undegradable fraction (U), effective degradability (ED), and rumen bypass or rumen undegradability (RU)) of dry matter.

Feed	K_d (% h^{-1})	Sf	D	U	ED	RU
		g kg^{-1} DM				
G	3.3 b	186 b	315 a	499 b	320 b	680 a
ALF	8.1 a	210 ab	284 ab	506 ab	398 a	602 b
DU	7.1 a	210 a	194 b	597 a	333 b	670 a
NM	7.2 a	202 ab	285 a	512 ab	387 a	613 b
SE	2.5	1.6	6.6	6.2	4.0	4.0

a - b In a column means followed by different letter are significantly different as determined by Tukey's test ($P < 0.05$).

degradable fraction (D) of dry matter than western wheatgrass and NM winterfat while alfalfa was intermediate ($P > 0.05$). The undegradable fraction concentration was greater in DU winterfat ($P < 0.05$) than western wheatgrass while NM winterfat and alfalfa were intermediate ($P > 0.05$). Effective digestiblity (ED) for alfalfa and NM winterfat were greater ($P < 0.05$) than western wheatgrass and DU winterfat. Rumen undegradability showed the reverse trend to ED.

Degradation rate of D for NDF (Table 7.3) was similar ($P > 0.05$) for all feeds. The DU winterfat had less Sf ($P < 0.05$) than the other feeds. Western wheatgrass had more slowly degradable fraction (D) and less undegradable fraction (U) ($P < 0.05$) indicating more slowly digestible fibre than the winterfat seed sources or alfalfa. Effective degradability was less ($P < 0.05$) for DU winterfat than NM winterfat or western wheatgrass with alfalfa being intermediate ($P > 0.05$). Again species ranking for RU was the reverse of ED.

Crude protein degradation rates (K_d CP; Table 7.4) did not differ ($P > 0.05$) between species but the two winterfat sources tended to have a more rapid degradation rate than western wheatgrass. The soluble fraction (Sf) of CP was higher for DU, NM and alfalfa than for western wheatgrass ($P < 0.05$). The slowly digestible CP component did not differ for the feeds ($P > 0.05$). Alfalfa and the two winterfats had greater concentration ($P < 0.05$) of the soluble CP fraction. Western wheatgrass and DU winterfat contained greater concentrations of undegradable CP ($P < 0.05$) than alfalfa or NM winterfat. The rumen bypass fraction had the same trend with western wheatgrass and DU winterfat exhibiting a greater ($P < 0.05$) concentration than alfalfa and NM winterfat. The effective digestibility was lower ($P < 0.05$) in western wheatgrass and DU winterfat than alfalfa and NM winterfat. Due to the relatively low concentrations of crude protein, its degradation was difficult to measure. Western wheatgrass CP was only 37 g kg^{-1} DM compared to CP content for both winterfats and alfalfa, which were 3 to 6 times greater. Effective degradability had the opposite trend of RU.

Differences in components were consistent with other observations made for grasses and legumes (Jones and Wilson 1987; Minson 1982, 1987, 1990; Yu et al. 2004). The

Table 7.3: Effects of species (two winterfat plant types (DU, NM), western wheatgrass (G) and alfalfa (ALF) on *in situ* rumen degradation characteristics (soluble fraction (Sf), slowly degradable fraction (D), degradation rate of D (K_d), undegradable fraction (U), effective degradability (ED), and rumen bypass or rumen undegradability (RU)) of NDF.

Feed	K_d (% h^{-1})	Sf	D	U	ED	RU
		------------	------------	g kg^{-1} NDF	------------	------------
G	3.1	8 a	469 a	523 b	202 a	798 b
ALF	4.0	3 a	256 b	741 a	131 ab	869 ab
DU	5.4	-60 b	185 b	875 a	46 b	954 a
NM	5.1	-18 a	256 b	719 a	148 a	852 b
SE	1.4	3.1	13.1	15.4	6.9	6.9

a - b In a column means followed by different letter are significantly different as determined by Tukey's test ($P < 0.05$).

Table 7.4: Effects of species (two winterfat plant types (DU, NM), western wheatgrass (G) and alfalfa (ALF) on *in situ* rumen degradation characteristics (soluble fraction (Sf), slowly degradable fraction (D), degradation rate of D (K_d), undegradable fraction (U), effective degradability (ED), and rumen bypass fraction or rumen undegradability (RU)) of crude protein.

Feed	K_d (% h^{-1})	Sf	D	U	ED	RU
		------------	------------	g kg^{-1} CP	------------	------------
G	2.3	-85 b	340	699 a	116 b	884 a
ALF	8.5	441 a	372	188 b	694 a	306 b
DU	12.9	248 a	256	485 a	450 b	550 a
NM	10.6	390 a	349	259 b	633 a	367 b
SE	4.9	18.0	7.3	19.0	21.4	21.4

a - b In a column means followed by different letter are significantly different as determined by Tukey's test ($P < 0.05$).

alfalfa and western wheatgrass were more mature than material used by Yu et al. (2004) as indicated by a greater amount of U, lower ED and greater RU for CP. Legumes are known to have higher levels of soluble carbohydrates and proteins (Jones and Wilson 1987). Jefferson et

al. (2004) noted an *in vitro* organic matter digestibility for dryland western wheatgrass at Swift Current of 502 g kg^{-1} DM, a value similar to 501 g kg^{-1} DM observed for this trial (Sf + D (Table 7.2)). Degradation of NM winterfat and alfalfa were similar and this would agree with observations made by Nunez-Hernandez et al. (1989) who compared NM winterfat leaves with alfalfa hay. The difference between DU and NM winterfat in this study was likely confounded by stage of maturity. As plants mature, fibre concentration increases and crude protein concentration declines as does digestibility (Deinum 1973; Jones and Wilson 1987; Kilcher 1981; Minson 1990). Although both winterfat plant types were harvested on the same date, the phenological stages were not the same (see chapter 3). DU plants were fully mature by the November sampling dates and had completed seed production while NM plants were still vegetative or in the early bud stage.

The higher amounts of RU component for CP concentrations of DU winterfat could potentially benefit animal performance. Bohnert et al. (2002) noted CP supplements with 20 to 60% undegradable intake protein could be utilized by ruminants consuming low-quality forage.

7.3.2 Poly-Culture Comparison, Experiment 2

Overall, the runs or replicates in time (T) were only statistically significant ($P < 0.05$) for NDF degradation (Table A12) and then only for U, ED and RU. This was attributed to random error. The Steer (St) and Feed x Steer interaction were not significant ($P > 0.05$).

The K_d for DM (Table 7.5) was greater ($P < 0.05$) for alfalfa and the mixture with 50% winterfat than for western wheatgrass while the DU winterfat and the 20% winterfat mixture were intermediate ($P > 0.05$). Western wheatgrass had a lower concentration (P <

Table 7.5: Effects of species (winterfat (DU), western wheatgrass (G) and alfalfa (ALF)) and two species mixtures (20%G/30%ALF/50%WF, 50%G/30%ALF/20%WF) on *in situ* rumen degradation characteristics (soluble fraction (Sf), slowly degradable fraction (D), degradation rate of D (K_d), undegradable fraction (U), effective degradability (ED), and rumen bypass fraction or rumen undegradability (RU)) of dry matter.

Feed	**K_d (% h^{-1})**	**Sf**	**D**	**U**	**ED**	**RU**
		---------- g kg^{-1} DM	----------	----------	----------	----------
G	3.2 b	146 c	346 a	507 bc	298 d	702 a
ALF	10.0 a	222 ab	191 b	587 a	358 bc	641 bc
DU	6.8 ab	257 a	277 ab	467 c	429 a	571 d
20%G/ 30%ALF/ 50%WF	8.0 a	210 b	255 ab	535 ab	376 b	624 c
50%G/ 30%ALF/ 20%WF	5.7 ab	189 bc	264 ab	547 ab	339 c	660 b
SE	2.7	4.7	6	4.2	5	5

a - b In a column means followed by different letter are significantly different as determined by Tukey's test ($P < 0.05$).

0.05) of the DM Sf than the other feeds except the mixture with 20% winterfat, which was intermediate (P > 0.05) between the western wheatgrass and the mixture with 50% winterfat. DU winterfat had a greater (P < 0.05) concentration of DM Sf than both mixtures and the wheatgrass for DM . Alfalfa had an intermediate (P > 0.05) concentration of D between DU winterfat and both mixtures. Alfalfa had a lower (P < 0.05) concentration of D (191 g kg^{-1} DM) than western wheatgrass (346 g kg^{-1} DM). DU winterfat and both mixtures had intermediate concentrations of D (P > 0.05). The undegradable fraction was similar (P > 0.05) for the mixtures, alfalfa and western wheatgrass. The DU winterfat had lower (P < 0.05) U concentration of DM than alfalfa or both mixtures. The U concentration of DM for the mixtures were intermediate (P > 0.05) for the grass and alfalfa while the grass was intermediate (P > 0.05) between DU winterfat and the mixtures. Effective degradability of DM was lowest (P < 0.05) for western wheatgrass (298 g kg^{-1} DM) and highest for DU (429 g kg^{-1} DM).The alfalfa and both mixtures were intermediate in ED of DM with the 50% winterfat mixture greater (P < 0.05) than 20% winterfat mixture with alfalfa intermediate to the mixtures. Rumen by pass fraction (RU) of DM exhibited the reverse trend of ED.

The degradation rate (K_d) for NDF (Table 7.6) was similar for all feeds (P > 0.05) although a numerical similarity existed between DU winterfat and the mixture with 50% winterfat. DU winterfat had a higher (P < 0.05) Sf concentration of NDF than the mixture with 20% winterfat. Alfalfa, western wheatgrass and the 50% winterfat mixture were intermediate (P > 0.05) in Sf of NDF. Western wheatgrass had a greater (P < 0.05) concentration of D for NDF (474 g kg^{-1} NDF) than alfalfa (143 g kg^{-1} NDF) and the mixture with 50% winterfat (254 g kg^{-1} NDF) . The DU winterfat and the mixture with 20% winterfat had intermediate (P > 0.05) D concentrations for NDF. DU winterfat had a lower (P < 0.05) concentration of U for NDF than alfalfa, western wheatgrass or both the mixtures. Effective degradability of NDF was greatest (P < 0.05) for DU winterfat (370 g kg^{-1} NDF) with the other feeds ranging from 120 to 205 g kg^{-1} NDF. Rumen bypass fraction (RU) had the opposite trend of ED as the mixtures exhibited 826 g kg^{-1} RU NDF and alfalfa exhibited 894 g kg^{-1} RU NDF.

Table 7.6: Effects of species (winterfat (DU), western wheatgrass (G) and alfalfa (ALF)) and two species mixtures (20%G/30%ALF/50%WF, 50%G/30%ALF/20%WF) on *in situ* rumen degradation characteristics (soluble fraction (Sf), slowly degradable fraction (D), degradation rate of D (K_d), undegradable fraction (U), effective degradability (ED), and rumen bypass fraction or rumen undegradability (RU)) of NDF.

Feed	K_d (% h^{-1})	Sf	D	U	ED	RU
		---------- g kg^{-1} NDF ----------				
G	2.5	18 ab	474 a	510 b	203 b	797 a
ALF	4.3	24 ab	143 b	833 a	106 b	894 a
DU	7.3	159 a	350 ab	494 b	370 a	630 b
20%G/ 30%ALF/ 50%WF	7.4	20 ab	254 b	725 a	175 b	826 a
50%G/ 30%ALF/ 20%WF	4.9	- 2 b	325 ab	673 a	174 b	826 a
SE	3.2	1.7	10.9	12.2	9.1	9.1

a - b In column means followed by different letter are significantly different as determined by Tukey's test (P < 0.05).

Table 7.7: Effects of species (winterfat (DU), western wheatgrass (G) and alfalfa (ALF)) and two species mixtures (20%G/30%ALF/50%WF, 50%G/30%ALF/20%WF) on *in situ* rumen degradation characteristics (soluble fraction (Sf), slowly degradable fraction (D), degradation rate of D (K_d), undegradable fraction (U), effective degradability (ED), and rumen bypass fraction or rumen undegradability (RU)) of crude protein.

Feed	**K_d (% h^{-1})**	**Sf**	**D**	**U**	**ED**	**RU**
		----------	----------	g kg^{-1} CP	----------	----------
G	3.3	- 5 b	657 a	347	237 c	763 a
ALF	nc	nc	nc	nc	nc	nc
DU	7.5	395 a	217 b	387	474 b	526 b
20%G/ 30%ALF/ 50%WF	11.7	518 a	128 bc	353	606 a	394 c
50%G/ 30%ALF/ 20%WF	2.7	589 a	62 bc	349	614 a	386 c
SE	5.6	26	33.6	20.8	16.7	16.7

a - c In a column means followed by different letter are significantly different as determined by Tukey's test ($\alpha = 0.05$).

nc - did not converge after 200 iterations

No values were reported for alfalfa crude protein degradation (Table 7.7) due to failure of alfalfa data to converge after 200 iterations indicating a failure to reach a detectable plateau. Alfalfa may have required longer than the 72 h, used in this study, to plateau. No differences ($P > 0.05$) for K_d of crude protein were detected but the mixture with 50% winterfat tended to be higher (11.7 % h^{-1}). Soluble fractions (Sf) were similar ($P > 0.05$) for DU winterfat and the mixtures (395 to 589 g kg^{-1} CP) and greater ($P < 0.05$) than western wheatgrass (- 5 g kg^{-1} CP). The DU winterfat (217 g kg^{-1} CP) had lower concentration of D ($P < 0.05$) than western wheatgrass (657 g kg^{-1} CP). Both mixtures had numerically less ($P > 0.05$) D than DU winterfat. The U fraction was similar ($P > 0.05$) for the grass, DU winterfat and both mixtures. Effective degradability was lowest ($P < 0.05$) for western wheatgrass. The mixtures had greater ED of CP ($P < 0.05$) than DU winterfat. DU winterfat was intermediate in ED of CP. Rumen bypass crude protein had the opposite trend.

Negative values for Sf of CP indicated a longer lag phase before digestion could be detected, often the result of slower attachment of appropriate micro-organisms (Huntington and Givens 1995). There are other modelling approaches which account for the lag phase but they can result in distortion of the curve and the *in situ* rumen degradation characteristics (Huntington and Givens 1995; Orskov 2000). Orskov (2000) suggested utilization of original method when negative Sf values occur and this was done in this study.

Overall we saw similar trends between the mono-culture comparison (experiment 1) and the poly-culture comparison (experiment 2) for alfalfa and western wheatgrass. The differences could be due to subsampling. This would be expected because they were from the same bulk sample. The 2003 DU winterfat was overall more digestible than 2002 DU winterfat. The increased digestibility resulted from more soluble DM, NDF and CP. Crude protein for winterfat was made up of larger concentrations of Sf and U, than D. Yu et al. (2004) observed a similar decrease in D associated with increases in Sf and U. As winterfat and alfalfa plants mature, the D concentration differentiates to become either Sf or U. Jones and Wilson (1987) noted that under drought conditions less fibre was formed for grass and legumes. This may have occurred in the DU winterfat. The results support winterfat's potential for forage production under xeric conditions.

The mixtures did not demonstrate any difference for observed degradability between them despite differing amounts of grass/winterfat content. However, they did have increased degradability when compared with western wheatgrass which indicates that they had a positive benefit. The results agree with reported improvement of nutritive value from adding forbs and/or shrubs to grass diets (Arthun et al. 1992a; McKell et al. 1990; Nunez-Hernandez et al. 1989; Otsinya 1984; Otsinya et al. 1982). The rumen bypass protein fraction for DU winterfat was high and indicates that protein was available for gastro-intestinal digestion by the animal and not the rumen microflora. Tremblay et al. (2000) note that increased value for alfalfa as a protein source could be enhanced by increasing rumen bypass. The indications of rumen undegradable protein and potential for bypass protein for winterfat was noted in both trials. Bohnert et al. (2002) found that 20-60% of rumen undegradable protein was utilized effectively by ruminants on a low quality forage.

When the ED is calculated from the mono-culture values for the mixtures, no synergy is noted for ED of DM (Table 7.8) however, there was a negative synergy or interference on digestion of NDF. This is likely occurring due to increased amount of lignified compounds in winterfat and alfalfa NDF found. The observed ED of CP is considerably higher than the calculated ED of CP which indicates a positive synergy. The microbial populations are likely utilizing greater amounts of CP available from the alfalfa and winterfat but not available from the western wheatgrass alone. Increasing winterfat content of the mixtures did not increase ED of CP whether calculated or observed nor did it increase the RU of CP which suggests a possible interaction with alfalfa. This requires further investigation. The steers were fed a meadow bromegrass/alfalfa hay diet which would result in microbial populations adapted to a grass/alfalfa substrate digestion but not to a winterfat substrate. Rumen microorganisms range in specialization and diet is the most important factor influencing the numbers and relative proportions of microbial species present in the rumen (Yokoyama and Johnson 1988). This adaptation to substrate likely

Table 7.8: Calculated[z] and observed ED (%) of DM, NDF and CP for species mixtures.

Feed Component	Mixture	Calculated	Observed
		------------------ $g\ kg^{-1}$ CP ----------------	
DM			
	20%G/30%A /50%WF	382	376
	50%G/30%A /20%WF	342	339
NDF			
	20%G/30%A /50%WF	257	175
	50%G/30%A /20%WF	207	174
CP			
	20%G/30%A /50%WF	519[y]	606
	50%G/30%A /20%WF	429[y]	614

[z] - calculated ED = (observed ED for G * %of G in mixture) + (observed ED for A * % of A in mixture) + (observed ED for WF * % of WF in mixture).
[y] - values used for alfalfa ED taken from mono-culture comparison (Table 7.4).

resulted in preferential utilization of the alfalfa and grass species and resulted in lower ED of CP as the winterfat concentration increased.

The RU fractions for crude protein of western wheatgrass appear large but can be attributed to the extremely low crude protein content (Table 7.1). Protein bound to lignocellulosic structures in secondary cell walls would be unavailable, in western wheatgrass until potentially released by low pH conditions in the small intestine.

7.4 Conclusion

Effective degradability and RU of DM and crude protein were similar for NM winterfat and alfalfa but different than DU winterfat and western wheatgrass. Western wheatgrass and DU winterfat had similar effective degradability and RU of DM and crude protein in 2002. NM winterfat and alfalfa had lower RU fractions. Effective degradability of NDF was greater for NM winterfat and western wheatgrass than DU winterfat with alfalfa being intermediate. The opposite trend was seen for RU. DU winterfat provided a greater amount of RU crude protein than did NM winterfat, the NM winterfat had greater degradability than DU winterfat.

The DU winterfat, in 2003, was different from western wheatgrass. The DU winterfat had the highest effective degradability for NDF and DM. Nutritive value of DU winterfat had improved under the xeric conditions encountered in 2003 compared to wetter 2002.

The mixtures were intermediate in effective degradability of DM and NDF between alfalfa/winterfat and western wheatgrass indicating a benefit for inclusion of either alfalfa and/or winterfat. The mixtures had higher effective degradability of crude protein than DU winterfat and western wheatgrass alone. The calculated ED compared to the observed ED indicated a negative synergy for degradation of NDF and a positive synergy for degradation of CP. Inclusion of alfalfa and winterfat increased CP of mixtures to levels adequate for a medium framed British breed replacement heifer in its first trimester, whereas western wheatgrass alone was deficient for CP. Further research is required to separate the alfalfa and winterfat contributions to the mixtures.

Mature DU winterfat appeared to be a good source of bypass protein and confirms its ability to provide a protein for the grazing ruminant animal during periods whenCP concentration is deficient in other available forage, such as in fall and winter.

CHAPTER 8
CONCLUSIONS

8.1 Winterfat Growth

Ecotypic differences are well-documented for winterfat over its range but most of the growth differences are described for plants within a limited geographical region, for example within the state of Utah. This thesis examined growth differences between a southern (New Mexico) versus a northern (Saskatchewan, DU ecovar™) growth form.

NM and DU winterfat plants differed in phenological progress towards maturity and their growth when grown at Swift Current, Saskatchewan. For plants established in 2001 NM plants were taller with greater individual plant dry matter during the first harvest season (2002). However, DU winterfat plants produced more biomass on a per hectare basis due to greater number of surviving plants in 2003. New Mexico winterfat plants failed to progress to a mature seed phenological stage while DU plants produced mature seed in excess of production figures reported for germplasm from Montana, USA. Results in the second year (2003) suggested that NM plants were sensitive to time of clipping but a clipping trial with appropriate controls is needed to confirm this observation.

Harvesting of DU material at 50% of height for the 2 years of this study indicated no deleterious effect during any of the clipping dates compared to Romo et al.'s (1995) observations for plants defoliated to a height of 5 cm (approximately 90% of height). The potential therefore exists for grazing of winterfat throughout the season if grazing were limited to 50% of height. The threshold for a deleterious effect may be higher than 50% of height but requires further investigation.

Both DU and NM plant types increased biomass productivity during the drought conditions of 2003 which demonstrates their forage potential during times when grass biomass is declining. This drought tolerance is due to drawing moisture from depth, decreased evaporation (Schwinning et al. 2003) and lower physiological activity (Moore et al. 1972).

Further research is required to identify additional potentially persistent germplasm and to identify additional differing growth characteristics found throughout winterfat's geographical range. Further research is needed to minimize the year-to-year variation in seed yield and ensure low-cost, reliable winterfat seed production. Seed production and seed cost will play a key role as to when winterfat will be accepted as a common forage crop. Until seed is consistently available, seed prices will stay high and thus discourage winterfat seeding.

DU winterfat plants demonstrated a superior persistence compared to NM plants did not. Therefore there exists genetic potential within the DU ecovar for further improvement of winterfat breeding material.

8.2 Winterfat Nutritive Quality

Nutritional variation within a species has been examined among cultivars but very little work has been done to examine potential nutritional differences among ecotypes within a wild species over its range of adaptation.

Fibre content, organic matter and digestibility differed between the plant types with NM having a better nutritive value. This was related to the NM plant's delayed maturity. Failure to reach the seed-set growth stage also played a role in the NM plants' mineral content. The result was two plant types with distinctive nutritional profiles as determined by chemical analysis but confounded by maturity. Additional germplasm with similar adaptation need to be tested for nutritional profile differences. The nutritional profiles of winterfat plants should be tested by grazing animals.

Crude protein, Mn, K, and S for both 2nd and 3rd year growth and DU and NM plants in 2003 fall period, met the nutritional requirements of a replacement Angus heifer in the first trimester. Plants experiencing only their first year of harvest also met the requirements for P. New Mexico plants met the Fe requirements. Magnesium was in excess for both DU and NM plants and Fe was in excess in DU plants.Supplementation of Ca, Cu, Co and Se for both ages of plant as well as Zn for older New Mexico plants and for both ages of DU plants should be considered to meet the nutritional needs of livestock.

Leaves of DU plants had better nutritional quality than the stems. The environment in which they grew had an effect on: 1) fibre accumulation because stems accumulate fibre at a slower rate than leaves in a hot dry year; and 2) crude protein decline because stems' crude protein declined slower in a hot dry year. Stem material also retained a greater proportion of its original crude protein value than leaves.

From a nutritional standpoint, additional research on the chemical makeup of a wide range of germplasm would be beneficial to identify superior germplasm for improved nutritive value. This research would best be done at a number of sites to determine site affects and reduce confounding effects of interactions.

8.3 Winterfat in Mixtures

Mixtures are usually more productive and provide more stable biomass production over time (Christian 1987; McNaughton 1993; Tilman et al. 1996; Chapin et al. 2000). Seeded forage mixtures with multiple functional groups can optimize livestock production on pasture (Masters 2002; Norman et al. 2002; Suszkiw 2004). A potential species mix could include: winterfat ideally providing the bulk of required protein, western wheatgrass providing mainly carbohydrate and alfalfa providing both carbohydrate and protein along with biological N for mixture sustainability.

Increasing winterfat component in the seed mixtures increased the amount of winterfat in the resulting plant community and forage biomass and decreasing western wheatgrass decreased its contribution. The resulting plant communities from all four seed mixes had crude protein levels adequate for maintenance of a medium framed British breed cow in its first trimester of gestation. A nutritional benefit for the mixtures of species compared to a monoculture of grass was evident with increased protein with the mixture of species.

The study on the potential of seeded mixtures would have benefitted from the use of DU winterfat rather than NM winterfat. Unfortunately seed availability prevented DU winterfat usage. Additional plant species need to be examined to develop a seeded species mixture in which species are more complementary to each other and to winterfat, ie. slower growing grasses and legumes. Another approach could be to increase the proportion of winterfat in the seed mix.

The year in which growth occurs had a major impact on chemical make up of the forage produced. The cool wet year of 2002 resulted in a mixed species forage with lower fibre and organic matter concentrations with increased crude protein concentration and organic matter digestibility compared to the hot dry year of 2003.

Effective degradability (ED) and rumen undegradability (RU) were similar for NM winterfat and alfalfa while DU winterfat was similar to western wheatgrass in 2002. In 2003, DU winterfat was different from western wheatgrass having the highest effective degradability for NDF and DM. Nutritive value of DU winterfat was greater under the xeric conditions encountered in 2003 than in 2002.

The *in sacco* results indicate that mixtures were intermediate in degradability of DM, NDF and crude protein between alfalfa or winterfat and western wheatgrass which indicates a similar benefit for inclusion of either alfalfa or winterfat. Inclusion of alfalfa or winterfat increased crude protein to levels adequate for a medium framed British breed replacement heifer in its first trimester, whereas western wheatgrass alone was deficient in crude protein. The calculated ED compared to the observed ED indicated a negative synergy for degradation of NDF and a positive synergy for degradation of CP.

Mature winterfat appears to be a good source of rumen by-pass protein. The growing environment does affect the digestive kinetics of winterfat.

Separation of the alfalfa from the winterfat effect is required in order to determine the contributions of alfalfa or winterfat to a shrub/legume/grass mixture. Appropriate proportions of species within a seeding mixture need to be determined for plant community establishment and optimization of nutritive value for livestock production. Research needs to be done to determine the effects of preferential species grazing if it occurs, and to determine animal gain. These mixtures were only an initial attempt to ascertain winterfat nutritive value and additional species mixtures need to be investigated. A longer time period is also required to examine sustainability and potential N transfer from legume to shrub.

Cutforth (2000) has identified warming of the climate has occurred in southwestern Saskatchewan. This coupled with predictions of increased aridity (Sauchyn et al. 2002) suggests a future climate conducive to drought-adapted plants. This thesis found winterfat had the ability to respond with increased growth, seed production and nutritional quality in the drought year of 2003 albeit in an artificial condition (landscape matting). As a future means to reduce risk of forage production failure under more arid conditions, evaluation of forage mixes containing winterfat should be initiated.

8.4 Summary

Winterfat, a native shrub of the Great Plains, is known to have ecotypic differences. Growth differences between a northern type (DU Canada ecovar™, DU) and a southern type (New Mexico seed source, NM) occurred when grown at Swift Current, Saskatchewan. DU plants were a more compact with denser growth form. DU plants were able to complete their growth cycle. In contrast, NM plants were unable to complete their growth cycle in this environment. NM winterfat maintained a higher crude protein concentration and organic matter digestibility than DU winterfat because of its prolonged vegetative growth stage. Winterfat grew best under hot dry conditions encountered in 2003, indicating its potential as a drought-adapted forage. The northern and southern plant types concentrated minerals at different rates and amounts. Of the 15 minerals tested only Ca, Cu, Co, Se and Zn would require supplementation if winterfat were utilized as a monoculture. Sulfur, Fe and Mg concentrations were above the requirements of a British medium framed breed heifer in her first trimester. These three minerals in excess amounts further reduce availability of Cu emphasizing the need for Cu supplementation if winterfat is used in pure stands. This is unlikely on the Canadian prairies at present seed costs. Furthermore, naturally occurring winterfat is not found in pure stands in the Canadian prairies.

Inclusion of winterfat with alfalfa increased the crude protein concentration of plant mixes containing western wheatgrass to levels which met the nutritional requirements of a British medium framed breed heifer in her first trimester. DU winterfat provided a good source of rumen undegradable protein for fall grazing. In a mixture with alfalfa and western wheatgrass, winterfat increased rumen undegradable protein concentration compared to that of mono-culture western wheatgrass during the fall grazing period.

DU winterfat should be a good source of crude protein and rumen bypass protein for animal utilization during the fall period when crude protein of other plants is often limited. Inclusion of winterfat and alfalfa in plant species mixes improves the crude protein status of the fall forage stand such that the nutritional needs of a medium framed British breed heifer in her first trimester are met when compared to mono-cultures of most grasses.

The limiting factors to increased utilization of winterfat will be regularly available seed at a reasonable cost and appropriate species to seed with winterfat.

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10. APPENDICES

Table A1: Stage of growth numeric score for statistical analysis.

Stage of growth	Numeric score
Vegetative	1
Bud	2
Bud/Flower	3
Bud/Seed	4
Flower	5
Bud/Flower/Seed	6
Flower/Seed	7
Seed	8
50% Seed Loss	9
Seed Disarticulated	10

Table A2: Fertilizer effect on mean canopy diameter, plant height, dry matter (DM) per plot, dry matter (DM) per plant and number of plants for seed sources, New Mexico (NM) and Ducks Unlimited ecovar™ (DU), as affected by date of clipping the second site first year of harvest and first site second year of harvest, 2003. The seed source by date of clipping interaction was significant ($P < 0.05$) thus results for individual seed sources shown.

	Canopy Diameter (cm)		Height (cm)		DM per plot (g m^{-2})		DM per plant (g)		Number of Plants per plot	
First harvest										
Seed Source	DU	NM	DU	NM	DU	NM	DU	NM	DU	NM
Fertilizer	48.9 a	21.6	33.4 a	20.6	648	21	68	5	10	3.3
No Fertilizer	45.1 b	18.4	31.4 b	22.5	571	26	59	6	10	3.4
SE	6.9	9.4	5.1	6.3	27.8	4.8	12.3	4.8	0.7	1.4
Second harvest										
Fertilizer	56.4	27.8	36.1	26.7	829	47	84	17	3	2
No Fertilizer	56.1	33.6	37	28	932	79	94	27	3	2
SE	7.6	13.7	5.9	8.7	17	6.9	34	10.6	1.7	1.3

Numbers followed by a different letter are significantly different ($P < 0.05$) as determined by the Tukey's test.

Table A3: Probabilities (Pr > F) of fertilizer effect for stage of growth data collected for Site 1 and 2 in 2002and 2003 of growth study .

2002 First harvest Experiment 1	2003 First harvest Experiment 2	2003 Second harvest Experiment 1
0.309	0.207	0.612

Table A4: Probabilities (Pr > F) for plant height, canopy, seed yield and stage of growth data collected for Site 1 in 2002 seed production study for DU seed source.

	Plant Ht.			Canopy		Seed	Stage of Growth		
Factor	July	Aug	Sept	Aug	Sept	Yield	July	Aug	Sept
Main Plot									
Rep	0.787	0.223	0.787	0.988	0.320	0.573	0.081	0.018	0.959
Water (W)	0.591	0.482	0.738	0.622	0.310	0.664	0.132	0.002	0.393
Sub-plot									
Fert-ilizer (F)	0.304	0.668	0.863	0.652	0.266	0.785	0.079	0.740	0.599
W*F	0.974	0.081	0.902	0.336	0.981	0.496	0.893	0.876	0.724
SE	6.7	5	5.6	8.5	9.2	12.1	1.4	0.9	0.4

Table A5: Probabilities (Pr > F) for plant height, canopy, seed yield and stage of growth data collected for Site 1 in 2002 seed production study for DU seed source.

	July	August	
Factor	Primary branches	Primary branches	Secondary branches
Main Plot			
Rep	0.954	0.922	0.833
Water (W)	0.633	0.959	0.454
Sub-plot			
Fertilizer (F)	0.298	0.408	0.147
W*F	0.065	0.108	0.271
SE	1.9	4.2	52.3

Table A6: Nutritional requirements for minerals for medium framed British breed replacement heifer in first trimester (NRC 2000).

Nutrient	Minimum requirement	Maximum tolerable
	-------------------------g kg^{-1} DM -------------------------	
Crude Protein	72	
Ca	2.3	
P	1.8	
K	6	30
Mg	1.2	4
Na	0.6 - 0.8	----
S	1.5	4
	---------------------mg kg^{-1} DM -------------------------	
Mn	40	1000
Zn	30	500
Cu	10	100
Fe	50	1000
Co	0.1	10
Se	0.1	2
Mo	----	5
Cd	----	0.5
B*	----	150

* - Boron limits from Black et al (1984), other mineral minimums and maximums from NRC (2000).

Table A7: Simple linear correlation coefficients for ADF and NDF correlated with stage of growth and primary and secondary branch diameters correlated with OMD for DU and NM winterfat plants in 2003.

Plant Age	Seed Source	X	Y	r	Probability
3 years old	DU	ADF	Stage of growth	0.97	$P < 0.05$
		NDF	Stage of growth	0.96	$P < 0.05$
3 years old	NM	ADF	Stage of growth	0.90	$P < 0.05$
		NDF	Stage of growth	0.90	$P < 0.05$
2 years old	DU	ADF	Stage of growth	0.91	$P < 0.05$
		NDF	Stage of growth	0.91	$P < 0.05$
	NM	ADF	Stage of growth	0.88	$P > 0.05$
		NDF	Stage of growth	1.00	$P < 0.05$
3 years old	DU	Primary branch diameter	OMD	0.98	$P < 0.05$
		Secondary branch diameter	OMD	0.99	$P < 0.05$
3 years old	NM	Primary branch diameter	OMD	0.82	$P > 0.05$
		Secondary branch diameter	OMD	0.90	$P < 0.05$

Table A8: Dry matter (DM) yield in 2001 for seeded, weed and total species by seed mix (winterfat(WF), alfalfa (A), western wheatgrass (G)).

Seed Mix	Seeded DM	Weed DM	Total DM
	----------	$g\ m^{-2}$	----------
5%WF/20%A/ 75%G	2.4	74.8	76.4
10%WF/40%A/ 50%G	9.2	98.4	106.8
20%WF/40%A/ 40%G	4	121.2	125.6
40%WF/40%A/ 20%G	5.2	88	93.2
SE	2.9	66.8	69.6

Numbers within column followed by different letter are statistically different ($P < 0.05$) as determined by Tukey's.

Table A9: Species composition (%) by seed mix (winterfat (WF), alfalfa (A), western wheatgrass (G)) in 2001.

Seed Mix	Canopy cover	WF	A	G	Weeds	Bare ground
	-------------------	-------------------	-------------------	%	-------------------	-------------------
5%WF/ 20%A/ 75%G	16.9	0.4	0.2	0.3	18	49.4
10%WF/ 40%A/ 50%G	28.1	1.1	0.4	0.4	28	40.6
20%WF/ 40%A/ 40%G	25.6	2.3	0.3	0.1	23.8	31.2
40%WF/ 40%A/ 20%G	29.4	3.8	0.3	0.1	25.9	39.4
SE	19.6	2.6	0.3	0.4	20	24

Numbers within column followed by different letter are statistically different ($P < 0.05$) as determined by Tukey's.

Table A10: Covariance structures (variance components (Simple), constant correlation (CS), first-order autoregressive covariance (AR(1)), first-order ante dependence covariance (ANTE(1)), and unstructured covariance (UN)) selected according to Littell et al. (1996) and Wang and Goonewardene (2004) criteria, for 2002 and 2003 dry matter yields (seeded species (SWT), weed (WWT) and total (TWT)), community composition (canopy cover, winterfat (WF), alfalfa (A), western wheatgrass (WWG), weeds and bare ground), ADF, and NDF. For both weeds and seeded plants organic matter (OM), organic matter digestibility (OMD), crude protein (CP) and total phosphorous (P).

Data Type	Covariance Structure
Seeded species DM	AR(1)
Weed species DM	AR(1)
Total DM	AR(1)
Canopy cover	SIMPLE
Winterfat	SIMPLE
Alfalfa	SIMPLE
Western wheatgrass	AR(1)
Weed cover	AR(1)
Bare ground	SIMPLE
ADF	SIMPLE
NDF	SIMPLE
OM Seeded species	SIMPLE
OM weeds	SIMPLE
OMD Seeded species	SIMPLE
OMD weeds	SIMPLE
CP Seeded species	AR(1)
P Seeded species	AR(1)
CP weeds	SIMPLE
P weeds	SIMPLE

Table A11: Probabilities for Time (T) Steer (St) and Feed (F) x St effects for DM, NDF and Crude Protein soluble fraction (S), slowly degradable fraction (D),degradation rate of D (K_d), undegradable fraction (U), effective degradability (ED), and rumen bypass or undegradable fraction (RU) for comparison of two winterfat plant types, western wheatgrass and alfalfa.

Feed	Digestion	Effect		
Component	kinetic	T	St	F x St
DM	K_d (% h^{-1})	0.12	0.13	0.22
	S (%)	0.24	0.35	0.41
	D (%)	0.06	0.78	0.46
	U (%)	0.07	0.98	0.52
	ED (%)	0.23	0.48	0.43
	RU (%)	0.23	0.48	0.43
NDF	K_d (% h^{-1})	0.3	0.42	0.81
	S (%)	0.35	0.43	0.82
	D (%)	0.09	0.92	0.65
	U (%)	0.14	0.94	0.77
	ED (%)	0.89	0.33	0.9
	RU (%)	0.9	0.33	0.9
Crude Protein	K_d (% h^{-1})	0.34	0.9	0.99
	S (%)	0.59	0.83	0.66
	D (%)	0.71	0.78	0.81
	U (%)	0.07	0.06	0.78
	ED (%)	0.39	0.6	0.71
	RU (%)	0.39	0.6	0.71

Table A12: Probabilities for Time (T) and Feed nested within Steer (F(S)) effects for DM, NDF and CP soluble fraction (S), slowly degradable fraction (D),degradation rate of D (K_d), undegradable fraction (U), effective degradability (ED), and rumen bypass or undegradable fraction (RU) for comparison of DU winterfat, western wheatgrass, alfalfa and 2 three species mixtures.

Feed Component	Digestion kinetic	Effect T	St	F x St
DM	K_d (% h^{-1})	0.52	0.96	0.92
	S (%)	0.47	1	0.15
	D (%)	0.46	0.53	0.63
	U (%)	0.55	0.28	0.79
	ED (%)	0.57	0.76	0.23
	RU (%)	0.57	0.76	0.23
NDF	K_d (% h^{-1})	0.08	0.17	0.61
	S (%)	0.4	0.41	0.44
	D (%)	0.86	0.11	0.52
	U (%)	0.02	0.13	0.61
	ED (%)	0.04	0.28	0.6
	RU (%)	0.04	0.28	0.6
Crude Protein	K_d (% h^{-1})	0.16	0.32	0.6
	S (%)	0.75	0.09	0.26
	D (%)	0.79	0.07	0.09
	U (%)	0.7	0.08	0.08
	ED (%)	0.85	0.32	0.11
	RU (%)	0.85	0.32	0.11

Table A13: Analytical parameters for mineral analyses.

Mineral	Analytical Instrument	Lamp (mA)	Wave-length (nm)	Flame/ Plasma gas	Gas Flow Rate	Optic/ Detector chamber	Stan-dards	Lower detection limit	Stan-dard Recali-bration Fre-quency	NIST[f] Re-ference Material	APG[g] Setpoint standard
Ca	ICPAES [a]	No lamp	317.9	Argon plasma and sheath gas	30 psi nebulizer pressure	Vacuum	5.0 to 100.0 ppm	2.5 ppm	Every 50 samples	Durum wheat flour 8436	Minerals #35895
K	FAAS[b]	3	766.5	Air / acetylene	1.7 L min^{-1}	No special conditions	1.0 to 8.0 ppm	0.5 ppm	Every 10 samples	none	Minerals #35895
Mg	ICPAES	no lamp	279.5	Argon plasma and sheath gas	30 psi nebulizer pressure	Vacuum	5.0 to 100.0 ppm	2.5 ppm	Every 50 samples	Durum wheat flour 8436	Minerals #35895
Na	FAAS	2.5	589	Air / acetylene	1.7 L min^{-1}	No special conditions	1.0 to 4.0 ppm	0.1 ppm	Every 10 samples	Durum wheat flour 8436	Minerals #35895

Table A13: Analytical parameters for mineral analyses (cont'd).

Mineral	Analytical Instrument	Lamp (mA)	Wavelength (nm)	Flame/ Plasma gas	Gas Flow Rate	Optic/ Detector chamber	Standards	Lower detection limit	Standard Recalibration Frequency	NIST[f] Reference Material	APG[g] Setpoint standard
S	ICPAES	no lamp	180.7	Argon plasma and sheath gas	30 psi nebulizer pressure	Vacuum	5.0 to 100.0 ppm	2.5 ppm	Every 50 samples	Durum wheat flour 8436	Trace metals #35624
Mn	ICPAES	no lamp	257.6	Argon plasma and sheath gas	30 psi nebulizer pressure	Vacuum	0.1 to 2.0 ppm	0.05 ppm	Every 50 samples	Durum wheat flour 8436	Trace metals #35624
Zn	ICPAES	no lamp	213.8	Argon plasma and sheath gas	30 psi nebulizer pressure	Vacuum	0.1 to 2.0 ppm	0.05 ppm	Every 50 samples	Durum wheat flour 8436	Trace metals #35624
Cu	GFAAS[c]	4	324.8	Electronic heating	Graphite tube argon wash	No special conditions	20.0 to 80.0 ppb	10.0 ppb	Every 6 samples	Durum wheat flour 8436	Trace metals #35624

Table A13: Analytical parameters for mineral analyses (cont'd).

Mineral	Analytical Instrument	Lamp (mA)	Wavelength (nm)	Flame/ Plasma gas	Gas Flow Rate	Optic/ Detector chamber	Standards	Lower detection limit	Standard Recalibration Frequency	NIST[f] Reference Material	APG[g] Setpoint standard
Fe	ICPAES	no lamp	259.9	Argon plasma and sheath gas	30 psi nebulizer pressure	Vacuum	0.2 to 4.0 ppm	0.2 ppm	Every 50 samples	Durum wheat flour 8436	Trace metals #35624
Co	GFAAS	7.5	240.7	Electronic heating	Graphite tube argon wash	No special conditions	10.0 to 40.0 ppb	5.0 ppb	Every 6 samples	Durum wheat flour 8436	Trace metals #35624
Se	HG-ICPAES[d]	no lamp	196	Argon plasma and sheath gas	25+ psi nebulizer pressure	Vacuum	5.0 to 100.0 ppb	20 ppb	Every 50 samples	Durum wheat flour 8436	Trace metals #35624
Mo[e]	GFAAS		313.3				1.0 to 10.0 ppm	1.0 ppm	Every 6 samples		
Cd	GFAAS	2.5	228.8	Electronic heating	Graphite tube argon wash	No special conditions	0.5 to 4.0 ppb	2.0 ppb	Every 50 samples	Durum wheat flour 8436	Trace metals #35624
B[e]	GFAAS		249.7				0.5 to 6.0 ppm	0.5 ppm	Every 6 samples		

Table A13: Analytical parameters for mineral analyses (cont'd).

[a] - inductively coupled (argon) plasma atomic emission spectroscopy done with a Baird Corporation ICP (reconditioned by questron Techmologies Corp. Mississauga, ON).
[b] - flame atomic absorption spectroscopy done with a Hitachi Z8200 Flame/Furnace atomic absorption spectrophotometer.
[c] - graphite furnace atomic absorption spectroscopy done with a Hitachi Z8200 Flame/Furnace atomic absorption spectrophotometer except Mo and B analyses.
[d] - hybrid generation - inductively coupled (argon) plasma emission spectroscopy done with a Baird Corporation ICP (reconditioned by questron Techmologies Corp. Mississauga, ON).
[e] - analyses done by Norwest Certified Laboratory, Edmonton, AB.
[f] - Durum Wheat Flour # 8436 reference material, U.S. Department of Commerce, National Institute of Standards and Technology, Gaitherburg, MD 20899.
[g] - Certified laboratory setpoint standard, Analytical Products Group, Inc. 2730 Washington Boulevard, Belpre, Ohio, 45714.

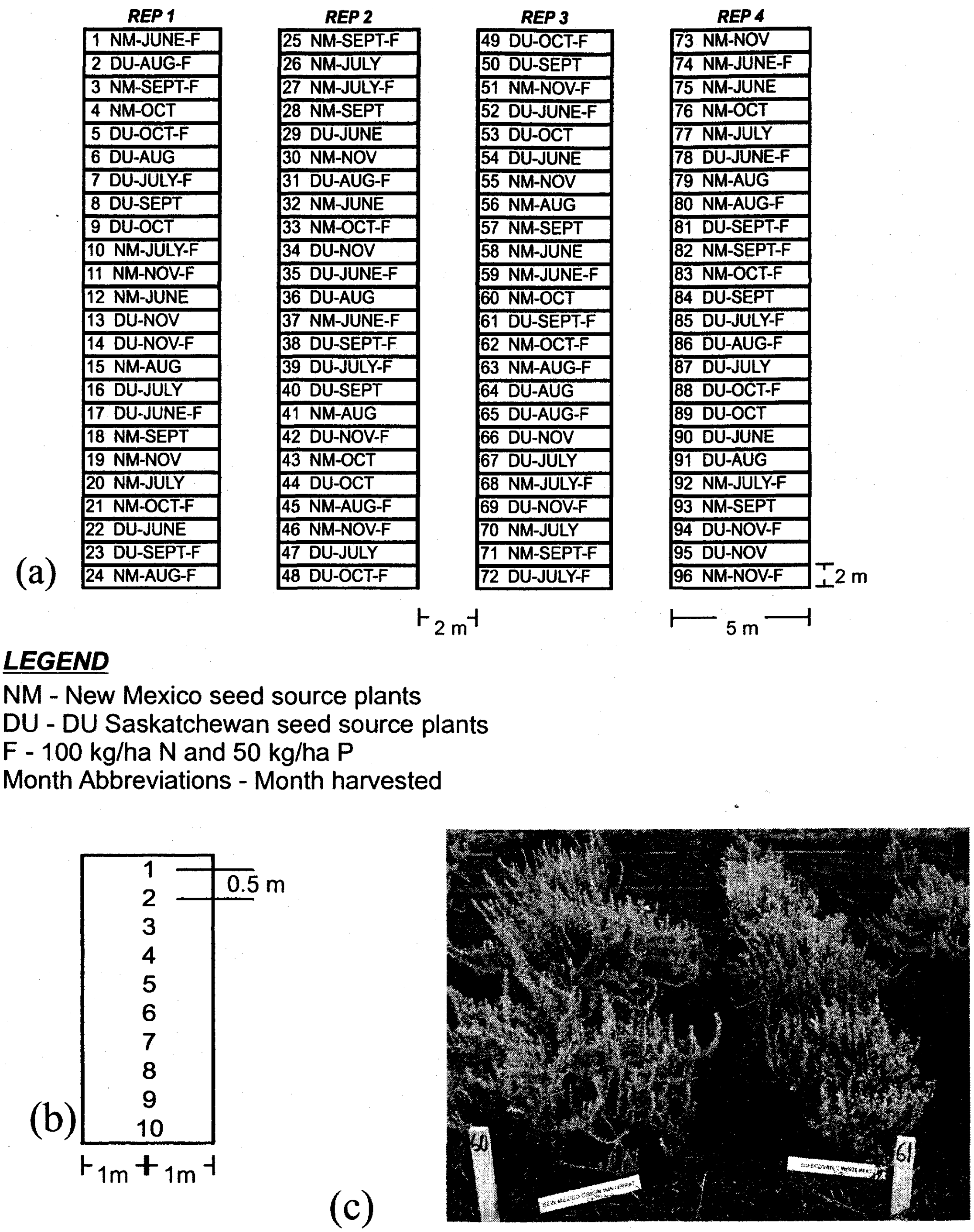

Figure A1: Growth experimental layout; (a) plots, replicates and treatments, (b) single plot and (c) two plots side by side.

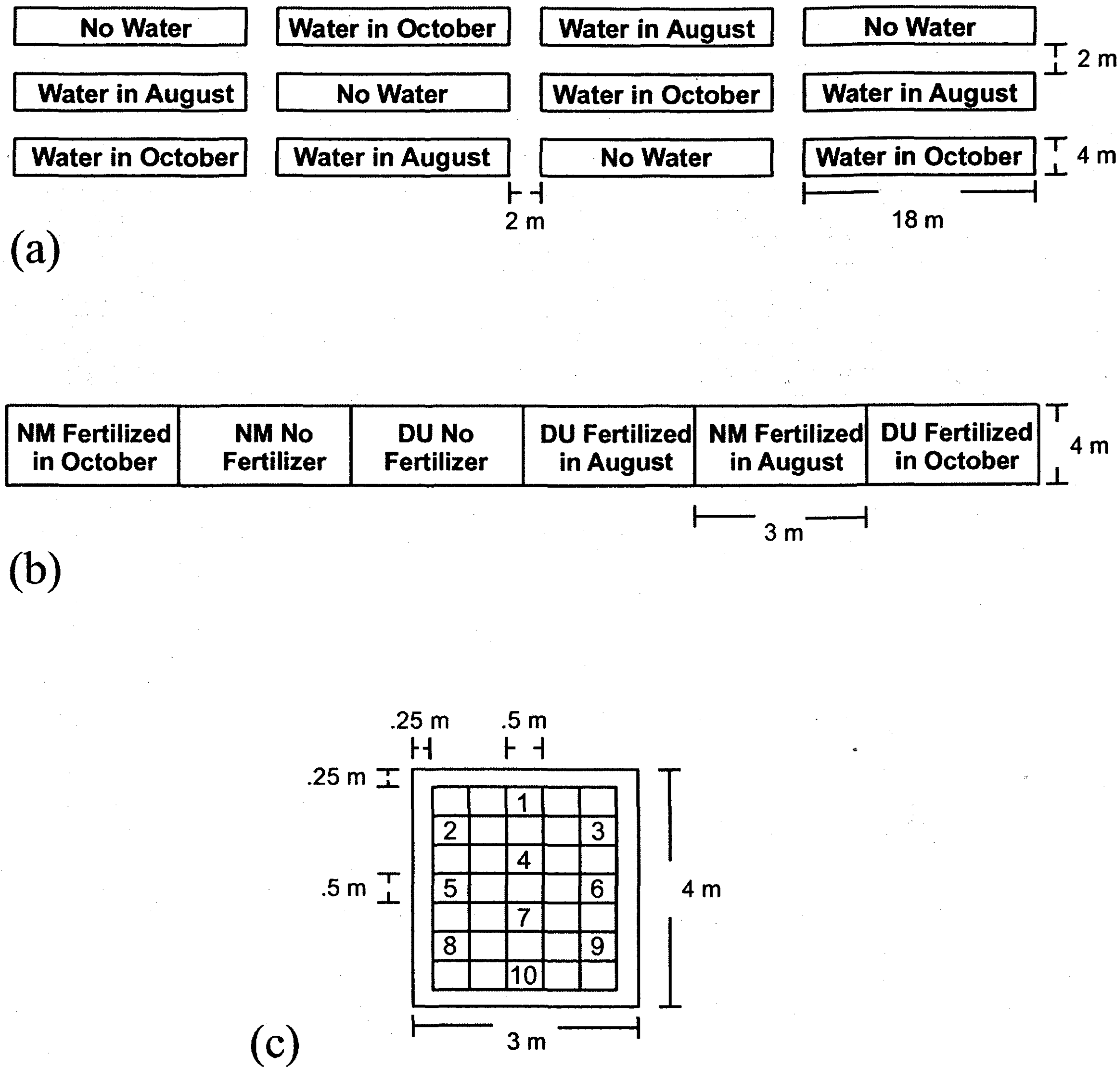

Figure A2: Experimental layouts for seed production studies; (a) main plots within replicates, (b) subplots with seed source and fertilizer treatments for a single main plot, and (c) single subplot with plant placement

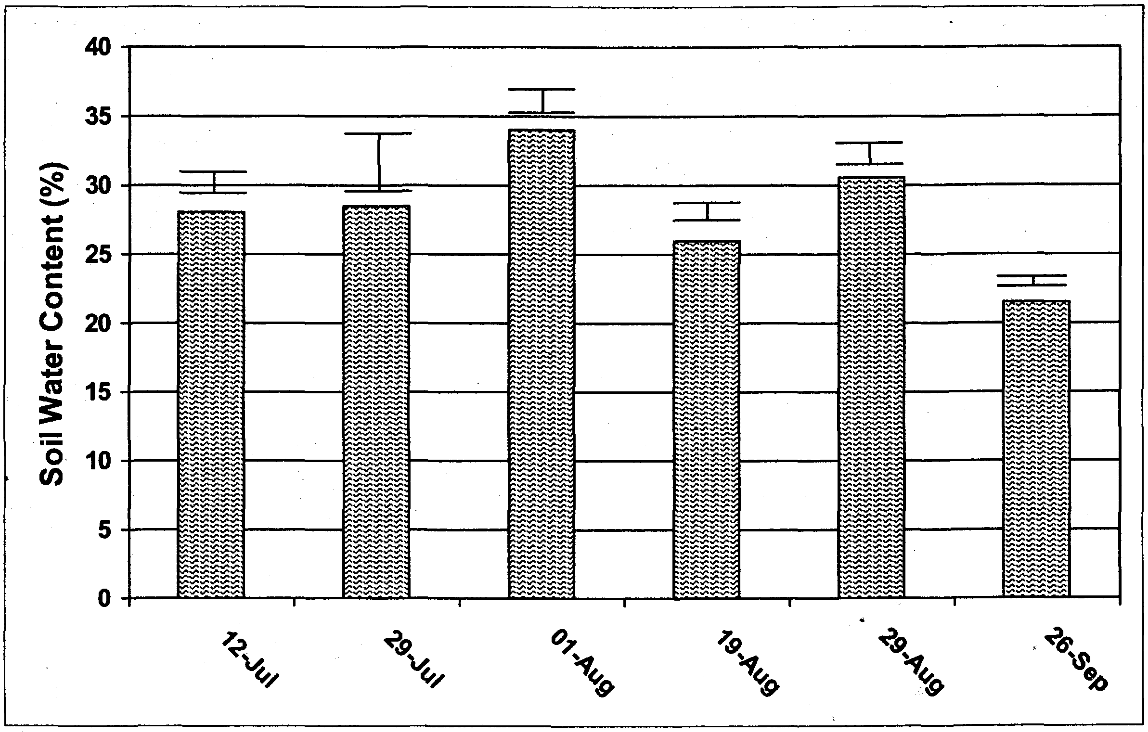

Figure A.3: Site 2 mean soil moisture readings (0 to 15 cm depth) for the 2002 growing season (12 July, 29 July, 1 August, 19 August, 29 August, and 26 September). No significant differences were detected for any factors (P > 0.05).

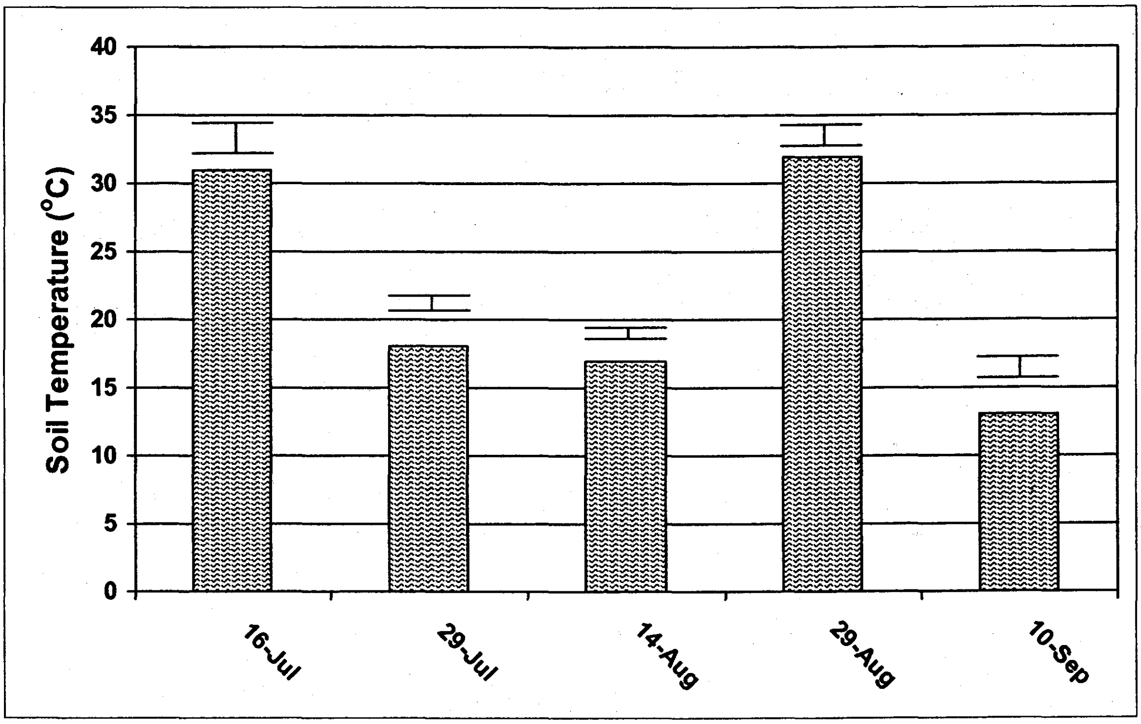

Figure A.4: Site 2 mean soil moisture temperatures from base of plants for the 2002 growing season (16 July, 29 July, 14 August, 29 August, and 10 September). No significant differences were detected for any factors ($P > 0.05$).

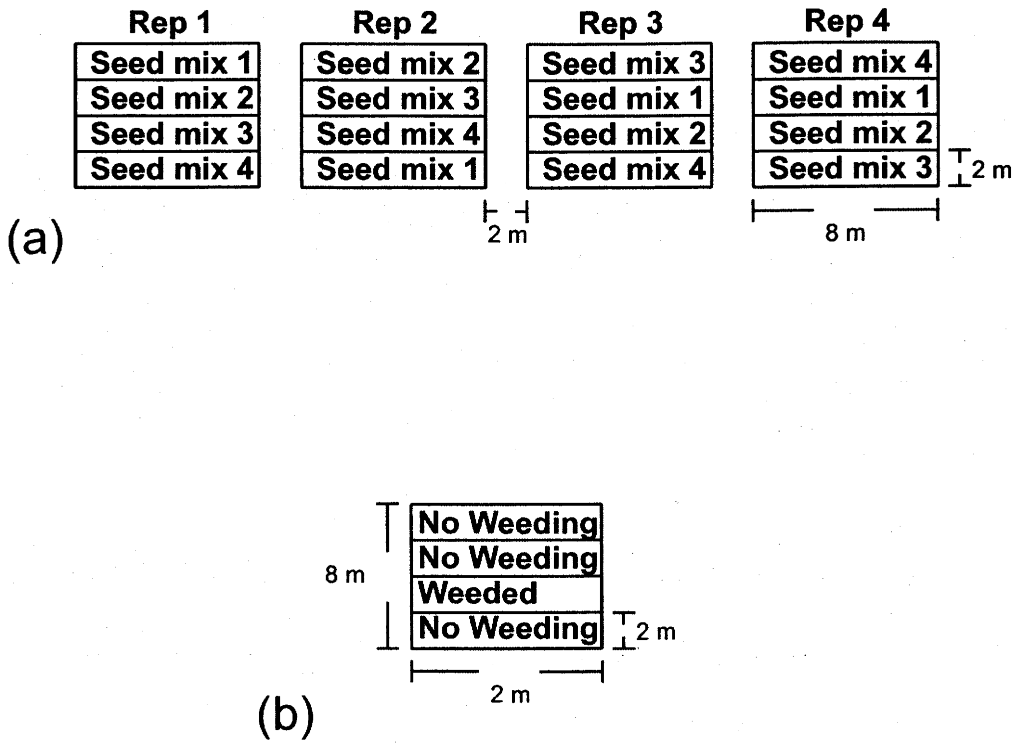

Figure A5: Experimental layout for seed mix study; (a) Main plots within replicates and (b) weeding treatment subplots for single seed mix main plot.